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The Implications of Ecosystem Management for Threatened and Endangered Species Conservation by the U.S. Army

by
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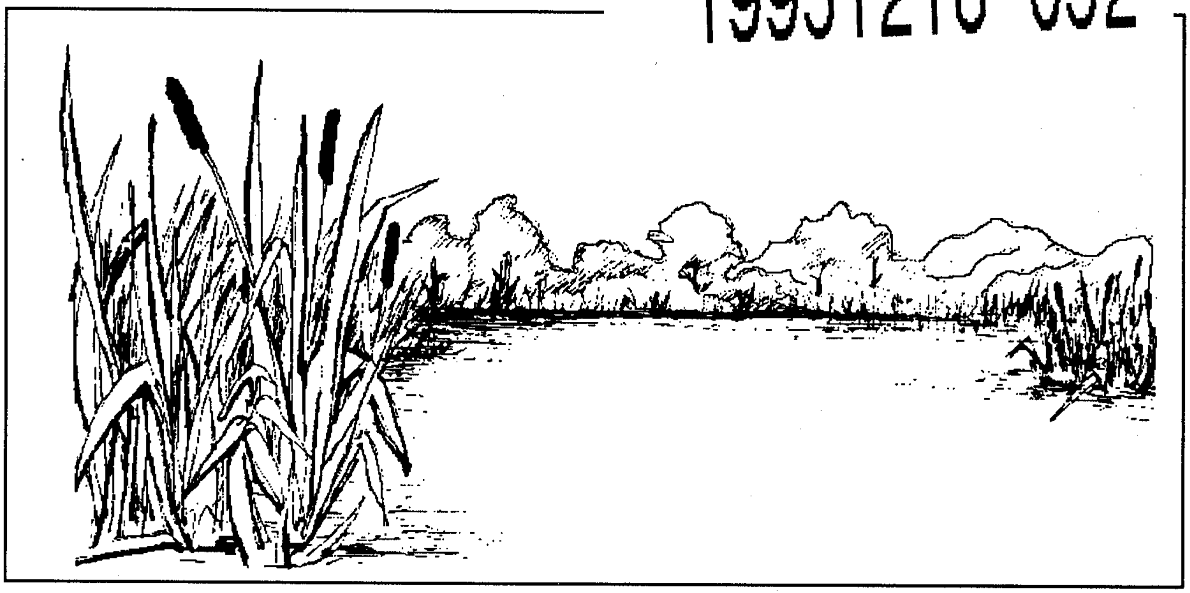

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Ecosystem management is a proactive, flexible, and efficient approach that can help reverse the processes that lead to declines in species populations and the resulting listing under the ESA.

This information on ecosystem management is for Army policymakers and installation land managers, for whom an understanding of ecosystem management can provide additional options for natural resources management and the conservation of threatened and endangered species.

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13. ABSTRACT (Maximum 200 words)

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Executive Summary

The U.S. Army manages the natural resources found on more than 11 million acres of land throughout the United States. Although the Army's primary mission is military preparedness, recent initiatives such as the *U.S. Army Environmental Strategy into the 21st Century* direct the Army to comply with all environmental laws and to conserve natural resources for future generations. That includes the management and conservation of threatened and endangered species (TES; both listed and candidate species) on lands that also must support military training or weapons testing or storage. This report introduces the concept of ecosystem management and its potential for balancing the requirements of TES with the requirements of military activity.

The concept of ecosystem management has developed as a consequence of recognized shortcomings in earlier conservation and land management efforts that focused narrowly on only a few elements of the natural world. Ecosystem management provides a new framework for land management that promotes intact and naturally functioning ecosystems, which can, by definition, support a wide array of native species (biodiversity) and demonstrate resilience in the event of a natural or human-induced disruption.

There is adequate justification for managing TES through an ecosystem approach. In fact, the conservation of ecosystems on which TES depend is a stated purpose of the Endangered Species Act (ESA). This is a rational approach to TES management, since many threats to species are not direct threats to individuals but rather are threats to habitat, ecosystem structure, or function. One of the most common threats is habitat modification or loss. By improving the condition of habitats, ecosystem management provides an effective and efficient alternative to single-species management. Furthermore, because ecosystem management recognizes that human activities are integral components of ecosystems, it provides the best opportunity for reconciling land use with conservation.

The concept of ecosystem management is a direct consequence of criticism of conservation policies of the past and of advances in the field of ecology. Ecology recognizes (1) the diversity and spatial and temporal variation in native habitat types, or ecosystems, (2) the important role of disturbance in maintaining many habitats, (3) the failure of past conservation strategies which aimed to preserve and protect ecosystems in a single "ideal" condition, and (4) the fact that even the largest preserves

in North America are not adequate to support a full range of native plants and animals through any ecologically meaningful length of time, when the external landscape is hostile to the species.

The concept of ecosystem management provides a new framework for land management that promotes conservation of communities and ecosystems and integrated planning. The goals of ecosystem management are to restore and maintain the holistic functional qualities of ecosystems, such as the complex interrelationships among ecosystem components and processes and ecological or biotic integrity. It recognizes multiple spatial and temporal scales, and emphasizes the importance of processes, rather than just organisms. Ecosystem management efforts should conserve TES to a large degree, although in the short term, intensive efforts are still anticipated for some TES. Even more importantly, ecosystem management can help reverse the processes that lead to species decline and listing under the ESA. It is a proactive, flexible, and efficient management approach for both TES conservation and the maintenance of functioning ecosystems that we depend on for natural resources, clean air and water, and other ecosystem services.

The transition to ecosystem management will be challenged by several technical hurdles:

1. Ecosystem management will be more effective if TES management is done over large geographic areas, beyond the boundaries of the installations
2. Ecosystem management will be more effective if managers have a thorough accounting of the native species, communities, and ecosystems that occur or would occur under natural conditions on their installations; it is a data-intensive approach
3. Native elements need to be understood well enough that their relative roles in the ecosystem can be evaluated, threats to their existence can be identified, and "focal elements" can be identified for detailed planning efforts
4. Management planning and activities should be shifted to a landscape scale, so that linkages and relationships among various regions of the installation can be recognized, and
5. A scientifically defensible, adaptive management monitoring framework will help capture advances in knowledge and improve management actions through a continuous feedback cycle.

Since many of the processes affecting ecosystems (such as migration, disease, gene flow, fire, and flooding) occur on or influence more than one site, ecosystem management should be planned on a landscape scale. It is important to identify units of land for planning based on ecological processes, not political jurisdictions. This will require

the cooperation of neighboring land owners and multiple agency coordination. The delineation of appropriate planning units will require regional inventory of flora and fauna, as well as regional assessments of ecosystem processes and interactions. Then identification of an appropriate planning unit and the long-term goal for that management unit (the "desired future condition") will become easier as data is assimilated.

Once managers know what species, communities, and ecosystems occur or potentially occur on their management unit, they can focus management objectives on the most critical components of the system for management planning, analysis, and decision-making. By choosing focal elements, managers streamline planning and clarify objectives. Selection of focal elements should be guided by the goals of ecosystem management. For the purpose of TES management, managers would most likely identify the landscape and ecosystem elements (either compositional, structural, or functional) that are essential for the conservation of TES populations. For example, a prairie dweller may require a certain length of grass for foraging habitat or a forest plant may require a certain fire regime to reproduce. Alternatively, entire habitats or communities (i.e., a certain group of forest-interior birds) might be chosen as focal elements. It is crucial that selection of focal elements supports the biotic integrity of the land.

Ecosystem management planning will place the requirements of TES or other focal elements within a landscape and ecosystem context, since large-scale influences affect management success. For these same reasons, ecosystem-based management will implement changes at the landscape level that integrate land use with natural ecological processes, such that the "desired future condition" is created and maintained. Conservationists are gaining consensus that pre-European settlement conditions should be restored as much as possible to facilitate TES conservation, although the working definition of "desired future condition" is determined through a political process that incorporates local culture, natural processes, and land use patterns.

Ecosystem management will also force an evaluation of the effects of human activities on TES populations and on ecosystem processes. Activities that degrade the integrity of the native ecosystems and decrease biodiversity will be inconsistent with ecosystem management. However, ecosystem management recognizes that change in composition, structure, and function is a natural process, within historical limitations. Thus, human enterprise that exists within natural limits and mimics or promotes natural processes is entirely consistent with ecosystem management. Human activities are an acceptable component of the ecosystems on military installations. By understanding how human activities compare to natural regimes, managers can discover compatible land use patterns, or can understand better how to mitigate and manage those lands that do not reflect natural processes, thus minimizing the potential damage.

Human activities and land use may be modified in support of ecological and biotic integrity. In most cases, this means the restoration of native species assemblages and the reintroduction of fire, hydrologic, or other natural disturbance regimes across the landscape. The spatial arrangement of land use and natural habitat may prove to be as critical as the amount of habitat created or conserved. Because of this, ecosystem management for TES may require habitat linkages across large expanses managed cooperatively by more than one landowner, thus spreading the responsibility for viable TES populations. In exchange, the enhanced resilience and health of the regional ecosystem should eventually stabilize TES populations to a point where small-scale impacts do not threaten the viability of the species as a whole. At this point, land use flexibility on Federal lands should increase.

To effectively monitor and improve ecosystem management efforts, an adaptive management philosophy should be incorporated. Since natural systems are always changing, and scientists know so little about natural systems processes, ecosystem management should be implemented as a learning process. We will never know everything about the ecology of every organism in an ecosystem. This is not necessary. Instead, the adaptive management process helps managers identify what critical characteristic or process must be understood or managed in order to sustain the whole system. The entire ecosystem management plan and monitoring program can be developed as a large-scale study, with strict protocols, experimental design, and statistical rigor. Various management options can function as experimental treatments, while appropriate ecological indicators are tracked through time. A suite of the most appropriate characteristics of the ecosystem should be used as indicators. They will differ among regions of the country and among ecosystems, but should reflect characteristics of concern to TES conservation, as well as descriptors of the ecosystem's structure and function.

An ecosystem approach is predicted to create major changes in two facets of Army natural resources management. First, the overall management goals will shift away from income generation through extractive land use, towards conservation of biodiversity, ecosystem health, and biotic integrity. Managers will incorporate a broad perspective and an awareness of the effects of their decisions at multiple spatial and temporal scales. Land use may be modified or rearranged to account for landscape-level interrelationships and processes.

Second, the Army will include the expertise of many other players in ecosystem management planning. If neighboring landowners are included in regional conservation efforts, TES management will be more efficient and effective. TES and their ecosystems will be considered in a regional context, which requires an understanding of the land outside of installation boundaries. The burden of data management can

be streamlined if multiple agencies coordinate their databases. Local experts may be hired to thoroughly identify installation TES, flora, fauna, and historical ecosystem processes. More sophisticated monitoring protocols can be implemented within a cooperative framework with other managers and researchers in order to continually increase understanding about ecosystems.

Ecosystem management will refocus management objectives away from commodity production towards the restoration of landscape-level habitat and ecosystem processes. This will result in more stable, resilient natural systems that include more continuous and higher quality habitat for TES on a regional or landscape scale. Thus, ecosystem management potentially is a highly effective approach to the management of TES on Army lands.

A change to ecosystem management will have an effect on the training community and on the ability of troops to train. In the short term, ecosystem management will probably increase the responsibility of the training community to evaluate and manage training impacts, as biodiversity considerations and ecosystem management become components of all land management decisions. Emphasis will probably remain on TES in particular. New approaches to minimize impacts are needed, such as the attempt to mimic natural disturbance patterns when impacts are unavoidable. Ecosystem management should also provide improved data with which to make land use decisions. By understanding how ecosystems function, we can have a better understanding of impacts on TES and on other sensitive resources. When a decision is made that results in negative impacts to the ecosystem, land managers should have an improved ability to restore the system and protect its integrity. If the land is used in a sustainable manner, natural processes are facilitated, and landscape connectivity is established, then on a landscape or regional scale, habitat availability should stabilize, and populations and ecosystems should be able to recover from the perturbations they experience. Consequently, ecosystem management has the potential to increase flexibility for training under the ESA, compared to current compliance requirements. However, this increased flexibility will probably only exist in the medium- to long-term, and will depend on the health of installations' ecosystems and the effort demonstrated by personnel to implement a proactive ecosystem management strategy.

Foreword

This study was conducted for Deputy Chief of Staff for Operations and Plans under Military Interdepartmental Purchase Request (MIPR) No. E87930341, "Effects of Army Training on Management of Threatened and Endangered Species." The technical monitor was Anthony Rekas, DAMO-TRO.

The work was performed by the Natural Resource Assessment and Management Division (LL-N) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. David J. Tazik is Acting Chief, CECER-LL-N; Dr. William D. Severinghaus is Operations Chief; and William D. Goran is Chief, CECER-LL. The USACERL technical editor was Gloria J. Wienke, Technical Resources Center.

COL James T. Scott is Commander and Acting Director, and Dr. Michael J. O'Connor is Technical Director of USACERL.

Contents

1 Introduction

Background

To achieve and maintain military preparedness, the U.S. Army uses more than 11 million acres of land throughout the United States. These lands and their natural resources have always provided tangible benefits to the Army and to the nearby public. The benefits include realistic training environments, the buffering of neighboring lands from Army activities, resources such as timber and game, and recreational opportunities. Army lands have sustained these benefits through natural resource management, or land management. In the past, the primary goal of land management was to supply products and services that directly and obviously benefit people.

Since the early 1970's, natural resource management has become increasingly influenced by societal concerns for conserving all native species of plants and animals, regardless of their known or immediate usefulness to human enterprise. The United States became the global leader in conservation when the Endangered Species Act of 1973 (ESA) was passed, which granted substantive protection from extinction to all listed flora and fauna. The continued existence of a species on public land cannot be jeopardized once it is listed as "threatened" or "endangered" under the ESA.

In the past 20 years, the public has become more aware of the value of biodiversity (biological diversity). The scientific fields of ecology and conservation biology have demonstrated the vital functions that biodiversity and ecosystems provide to people; clean air and water, genetic variability for crops and other resources, and a virtual warehouse of technological and medical advances yet to be discovered, among others. Today's land managers know that healthy ecosystems and biodiversity make up the foundation on which all other natural resources depend.

Threatened and endangered species (TES), both "listed" and "candidate" species, represent the elements of biodiversity that the United States is most in danger of losing. Although Army land managers may not have purposefully protected rare species in the past, agricultural conversion and urban sprawl are less pervasive on Army installations than on the surrounding landscape. Consequently, natural habitat remains relatively intact, and native and rare species exist to a remarkable extent on installations, even where heavy military training occurs.

The presence of rare native species, especially those listed under the ESA, presents a new land management challenge to the Army. Recent initiatives such as the U.S. Army Environmental Strategy into the 21st Century (U.S. Department of the Army [DA] 1992) direct the Army to immediately comply with all environmental laws (including the ESA) and to conserve biodiversity and natural resources for future generations. In addition, U.S. citizens have high expectations for the management of public lands, including the conservation of threatened and endangered species. To meet the challenge of TES conservation, while fulfilling the military mission (increasingly characterized by more intensive use on a shrinking land base), the Army must identify the most productive approach to TES management. Current thinking in Federal land management agencies and private conservation organizations suggests that ecosystem management provides the best chance for reconciliation of land use requirements (such as military training) and conservation of biodiversity, including TES. On August 8, 1994, the Office of the Under Secretary of Defense issued a memo calling for the implementation of ecosystem management in the Department of Defense (DOD; DUSD[ES]/EQ-CO memo, 8 August 1994). The intended audience for this report is Army policymakers and installation land managers, for whom an understanding of ecosystem management can provide additional options for natural resource management and TES conservation.

Objectives

The objectives of this research were to introduce the concept of ecosystem management and to provide an overview of the technical, scientific issues involved in using an ecosystem approach for the conservation of TES on Army installations. It will address the question: "What is the effect on training of taking an ecosystem-based approach rather than a species-based approach to management of TES?"

Approach

Researchers reviewed existing literature on ecological conservation and ecosystem management. They also examined technical fact sheets and position papers from other Federal agencies to identify concepts applied, approaches used, and lessons learned. Experts in ecosystem management from academia, government agencies, and The Nature Conservancy (TNC) were interviewed by telephone and their comments were incorporated into this report (see Appendix A for a list of experts interviewed). Many of the experts interviewed are familiar with military land management and TES issues on military lands. Based on these efforts, the general consensus of what ecosystem management entails and how it could be applied to Army installations is discussed.

Scope

This report is intended to be a discussion of the scientific issues raised by ecosystem-based management, and is not intended to address political, policy, or administrative issues. Non-science issues are as important as scientific issues, and in fact, are probably more urgent and difficult; an ongoing project through the Army Environmental Policy Institute (AEPI) is addressing some of the administrative and policy issues for ecosystem management (C. Foley, Senior Research Scientist, Army Environmental Policy Institute, professional discussion.).

Mode of Technology Transfer

It is recommended that the information in this report be used by Army policymakers, installation land managers, and training managers while developing ecosystem management approaches that will provide additional options for natural resources management and TES conservation.

Metric Conversion Factors

United States standard units of measure are used in this report. A list of metric (SI) conversion factors is included below for convenience.

1 acre = 0.4047 hectare
1 acre = 4,047 m^2

2 Why Ecosystem Management?

Ecosystem management is a useful, probably necessary, strategy for the conservation of TES. In fact, the ESA provides the legal basis for this approach. The first purpose of the ESA is "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved..." (16 USC Section 1531[b]), which appears to mandate the conservation of ecosystems. However, implementation of the law focuses on listing, protecting, and recovering individual species, not habitats or ecosystems. This reflects a past era when over-exploitation of vertebrates led to most population declines. Currently, loss of habitat (leading to changes in community and ecosystem structure and function) is the major cause of species decline and endangerment (Rohlf 1991). Although the status of many species has improved or stabilized due to protection under the ESA, the list of threatened, endangered, proposed, and candidate species continues to increase. This is partly because the ESA provides protection only to species that are already in danger of extinction. Populations of other species continue to decline due to factors such as habitat loss caused by economic development, certain ineffective management and conservation approaches, and increasing human population growth.

Although the ESA was originally intended to conserve species and ecosystems, implementation of the law on a species-by-species basis has been less effective than many people originally anticipated. Furthermore, experience has shown that protection of a species does not automatically translate into conservation of the habitat or ecosystem on which it depends (Noss 1991; Franklin 1993). Thus, many conservationists have called for a shift to the protection of communities, ecosystems, and landscapes. Species would then be conserved by maintaining their habitat, and species-level conservation would be framed in the context of the species' roles in ecosystems. These suggestions are not intended to replace the ESA's requirements, but to provide an alternative approach to meeting the goals of the ESA.

The ecological interrelationships between TES, biodiversity, and ecosystems are real. Failure to consider these connections in TES management has led to increasing conflicts between human activity and conservation, and disappointment in the implementation of the ESA to date. Failure to recognize the role of native organisms in providing ecosystem services such as clean air, clean water, and productive soils has led to catastrophic syndromes such as desertification, soil erosion, and toxification

around the world (Ehrlich and Mooney 1983). Thus, the greater perspective provided by ecosystem-based management is a meaningful improvement for both TES management in particular and conservation of all natural resources in general.

There are pragmatic reasons for instituting an ecosystem-based approach for TES management. First, an ecosystem approach is more efficient than a species-by-species approach. Conservation can take place at several scales: landscape, ecosystem, community, species, population, and genetic. As efforts are made at the smaller scale units, the expense increases and the chance for long-term success decreases (Scott, et al. 1987; Noss 1991; La Roe 1993). Second, when conservation is designed on an emergency, case-by-case basis, efforts to save one species may actually threaten another (Scott, et al. 1987; Pickett, Parker, and Fielder 1992). This leads to a kind of "triage" with the world's biodiversity that is extremely controversial from scientific and moral viewpoints (Noss 1983; Westman 1990; Chadwick 1991). Third, the United States does not have enough wilderness and parks (preserves) to conserve even a fraction of the TES that are now or may be listed under the ESA (Newmark 1985; Chadwick 1991; Wilcove 1993). An ecosystem approach provides the opportunity to conserve habitats before populations decline toward protected status and to integrate TES habitat into lands that are used for other purposes as well.

There is also a philosophical element in the call for ecosystem management. The past and current paradigm that separates people from nature cannot provide complete protection to TES, due to ever-increasing human population pressures. We need to improve the compatibility of human activities with conservation (Salwasser 1987; Noss 1991; Salwasser 1991) and to protect native plants and animals in areas we use for other purposes. The decades-old struggle between Muir's "preservationists" and Pinchot's "wise use" advocates is being replaced in some quarters by followers of Aldo Leopold's "Land Ethic," in which the close relationship between people and the land nourishes and enhances the welfare of both (Callicott 1990; Callicott 1991). This land ethic provides a philosophical foundation to ecosystem management.

3 The Scientific Foundation for Ecosystem Management

Ecologists have been interested in the biotic and abiotic factors responsible for species persistence and biological community structure for decades. As ecological concepts continue to emerge and be refined through research, they can be integrated into land use and conservation policy. Ecological theory about and evidence for community structure, ecosystem function and structure, and landscape-level processes provide the scientific foundation for ecosystem management.

A Community and Ecosystem Perspective

What is an ecosystem?

Very generally, an ecosystem encompasses all biological and physical matter, interactions, and processes within a defined area (King 1993). Ecosystems are geographical entities that include all living organisms and the abiotic environment. However, an ecosystem is also a concept, since the boundaries are arbitrary edges of an open system. The boundary might be the edges of an aquatic system such as a pond, or it might be the boundary of a certain geophysical-vegetative entity, such as an outwash plain. In natural systems, the edges are blurred and interdependent.

The concept of an ecosystem applies across hierarchical scales; a rotting log is an ecosystem, a prairie glade is an ecosystem, and the entire biosphere is an ecosystem (King 1993). Thus, organisms exist within many nested levels of ecosystems, depending on the spatial and temporal scales considered. In addition, ecosystems overlap and interact. Their behavior is highly dependent on the surrounding landscape, since ecosystems are open to inputs and disturbances (Golley 1993; King 1993).

The ecosystem concept includes the various processes that occur mostly, but not exclusively, within the boundary, usually referred to as "ecosystem processes." These include interactions between the biotic and abiotic components of the ecosystem, such as nutrient cycling, erosion, and sedimentation, as well as biotic interactions such as pollination, herbivory, competition, predation, disease, etc. (Samson 1992). Managers

can never understand the complexity of all ecosystem processes, nor can they directly "manage" them. But managers can develop an ecosystem perspective that recognizes the importance of these linkages.

An ecosystem is even more than the sum of its parts; species, processes, and interrelationships. Ecosystems are true systems that show emergent properties; ecosystem functions cannot be explained by the component parts alone. Just as glass, metal, electronics, and people all can be combined to create an airplane that flies, the components of an ecosystem (both living and nonliving) interact to perform such functions as nutrient cycling, moderation of environmental fluctuations such as floods, and the production of fertile soils, clean air, and clean water. These emergent properties include the qualities of self-organization and self-renewal (Ms. Kathy Jope, Chief of the Division of Natural Resources, Pacific Northwest Region, National Park Service, professional discussion, 11 October 1994; [hereafter referred to as "K. Jope"]).

Ecosystems are not static. They are dynamic and ever-changing in response to natural and man-induced disturbance regimes (Johnson and Agee 1988). In fact, under these natural regimes and at historic temporal and spatial scales, ecosystems are resilient systems capable of recovering from disturbances and maintaining identifiable components (Golley 1993). Past efforts to "fence off" a natural area and "protect" its desirable characteristics have repeatedly resulted in changes in composition, structure, and function (Botkin 1990).

What is a community?

A community is a group of living organisms connected to one another through ecosystem processes such as predation, animal pollination, herbivory, and competition. The concept of a community is closely related to the concept of an ecosystem. A community is the living part of an ecosystem, although it is sometimes subdivided into "plant community," "avian community," "soil microbe community," etc. Biotic communities exist as parts of a continuum. Boundaries between communities are fuzzy and the community composition is ever-changing. Ecosystems can easily contain multiple communities, but it is not necessary. Any geographical area that is considered a type of community can also be regarded as an ecosystem, once the abiotic components are included. A community is a real group of organisms, but it also serves as a construct to allow humans to understand and categorize the complex natural world.

Biotic communities are important elements in an ecosystem-based approach to TES management. Each species is adapted to its role in the functioning ecosystem; this role is called its "niche." TES and the other biotic components of these communities play

essential roles in nutrient cycling, energy flow, and food webs within ecosystems. Sometimes a single species will influence community and ecosystem processes far beyond the level expected from its abundance. These "keystone species" play a pivotal role in maintaining community composition and stability, including the maintenance of biodiversity in the community. For example, there is mounting evidence that invasions of certain species can alter not only community composition, but also ecosystem properties such as productivity, nutrient cycling, and hydrology (Vitousek 1990). Conversely, a change in community composition often is an easily recognized indication that ecosystem processes are compromised. In Virginia, long-term ecological studies are looking at the effects of nutrient cycles, spatial patterns, productivity, climatic variation, patch dynamics, and disturbance on species populations and distributions (Mr. Terry Cook, Ecologist, Texas Nature Conservancy, professional discussion).

One of the most important phenomena linking ecosystems, biotic communities, and individual species is the response of the biota to disturbance events and disturbance regimes. The response of a community and its associated species to disturbance depends on the frequencies, intensities, and timing of the disturbance combined with the life history strategies of the species available for recruitment or invasion (Niering 1987; Hobbs and Huenneke 1992). There are physiological limitations to a species' ability to survive disturbances, there are evolutionary limitations on the development of better-adapted species, and there are spatial and temporal limitations on the ability of an ecosystem to adjust to disturbance or change (Pickett, Parker, and Fielder 1992). If the natural frequency, intensity, or timing of disturbance is compromised, or the life history limitations of species are exceeded, the effect on ecosystem composition, structure, and function can be unpredictable as the system reorganizes.

For example, if historical events, such as climatic patterns, lightning, or human influence, created frequent fire, the native plants and animals in that ecosystem will have evolved mechanisms for survival and reproduction in fires, and will most likely out-compete nonadapted organisms as long as conditions remain similar to the historic regime. If fire is systematically suppressed, different species, better adapted to the new environment, may either invade the ecosystem or become dominant within the ecosystem. Such dynamics often lead to declines in native species populations and altered ecosystem processes and functions. In light of such phenomena, management strategies should attempt to maintain, or at least mimic, natural disturbance and ecological processes.

Recognition of ecosystem dynamics drives at least two facets of ecosystem management. First, the goal of ecosystem management is not to "preserve" an unchanging natural world. Instead, the concept of "natural" recognizes flux and change through

time and space. Conservation of rare species, habitats, and communities can be accomplished within a dynamic view of nature through ecosystem-based management choices and priorities (discussed more thoroughly in Chapters 4 and 5).

Second, ecosystem management recognizes that people are an intrinsic part of the natural world. Our actions are connected to the natural world through ecological linkages and interactions. We influence the flora, fauna, soils, and all ecological processes; and they influence us. Ecosystem-based management will develop plans and implement activities in full acknowledgment (but not in full knowledge) of our interactions with the natural ecosystems around us. This allows us to manage, harvest, and manipulate the natural world as recognized components of the ecosystem. It simultaneously demands that we assess the true impact of our activities in an ecosystem context as well.

A Landscape Perspective

To fully understand the importance of an ecosystem's response to any influence, the spatial and temporal context of the event must be considered at the landscape level. Many processes occur across a landscape, which can be regional in scope. A landscape contains many ecosystems, and many spatially distinct occurrences of those ecosystems. Landscape dynamics involve the flux of energy, minerals, and species among the component ecosystems and the resulting changes in those ecosystems (Forman and Godron 1981). The landscape perspective is essential since events that impact particular ecosystems may originate in part or in whole outside their boundaries (Pickett, Parker, and Fielder 1992). In the jargon of landscape ecology, each ecosystem can be considered a "patch" (e.g., a habitat patch). The occurrence of a disturbance on any given patch is not as important as the general compositional continuity over the entire landscape. In other words, the landscape may retain its identifying characteristics while individual patches change state through time (Pickett, Parker, and Fielder 1992).

The relationship of ecosystems/patches to landscape continuity is an elusive concept, especially when coupled with the arbitrary and variable nature of ecosystem boundaries. An example may be illustrative. In southern Illinois, the northeastern reaches of the Ozark hills have historically been covered with native oak-hickory forests. At one scale, the entire region fitting that description could be considered an ecosystem. Historically, it experienced a certain frequency of fire, rainfall, treefall gaps, and fragmentation across a very large geographical area.

Examination of the southern Illinois landscape at finer scales reveals many lakes, streams, and swamps. Each of these entities could be considered an ecosystem, or a patch, with its characteristic nutrient flows, species composition, and recovery patterns following disturbance. The aquatic systems retain individual system properties, but are greatly influenced through land use patterns, fire, and hydrologic cycles on nearby terrestrial systems. A stream's biodiversity will be affected by nutrient inputs from leaf fall. Stream bed erosion will be different according to the age of forest on nearby hillsides.

Scattered on bluffs and hillsides are the grassland systems, creating different patches on the landscape. These ecosystems are established where thin soils and drainage patterns fail to support trees. They are linked to the surrounding forests through predator-prey interactions, nutrient flows, species invasions, etc.

And of course, there are also many patches of woodland in various successional stages, spread throughout the landscape that are due to natural disturbances or from land use patterns. These patches will change through time, disappearing and reappearing throughout the larger oak-hickory ecosystem. The young forest patches provide habitat for certain species that are adapted to the high light, open environments of early successional communities. They are characterized by having different nutrient cycles, different species, and a different structure than older sections of the forest.

The fact that some sections of oak-hickory forest are younger than others, and that the locations of those patches change through time (patchiness in space and time) does not change the characteristic of the oak-hickory forest at the landscape scale (landscape continuity). It is with this perspective that ecosystem managers try to reconcile land use, natural variability, and specific goals such as ecosystem integrity, biodiversity, and TES conservation. To conserve the natural world, managers do not need to preserve it in a fixed state through time.

Landscape-level phenomena can be studied, described, and quantified. The relationship between patches and physical environmental variables can be evaluated, changes in patch edges can be monitored, adjacency patterns can be quantified, and the degree of fragmentation can be identified. Once landscape phenomena are quantified, models can be used to predict the landscape's response to land use or natural events (an excellent review of landscape ecology research can be found in Turner 1989). The integration of landscape ecology with community and ecosystem ecology completes the scientific basis upon which ecosystem management practices can be formulated.

4 What Is Ecosystem Management?

The concept of ecosystem management is still being defined by conservationists and resource managers. It is a conceptual approach for integrating human activities into naturally functioning systems (K. Jope; Ms. Jora Young, Director for Science and Stewardship, Florida Nature Conservancy, professional discussion) that will shift management emphasis from income generation to conservation of ecosystem process and services. In response to criticisms of single-species conservation efforts, ecosystem management promotes habitat conservation and integrated planning. A major difference between single-species management and ecosystem management is in the definition of the goal. Single-species management efforts usually are limited to producing a target population level of one species in a specific area. In contrast, ecosystem management strives to enhance more holistic, systemic qualities of an ecosystem, such as biodiversity, ecosystem health, and biotic/ecologic integrity. The DOD defines ecosystem management as a goal-driven approach to restoring and sustaining healthy ecosystems and their functions and values using the best science available. DOD's stated goal is to preserve, improve, and enhance ecosystem integrity in order to maintain and improve the sustainability and native biological diversity of terrestrial and aquatic, including marine, ecosystems while supporting human needs, including the DOD mission (DUSD[ES]/EQ-CO memo, 08 Aug 1994).

Biological diversity, or biodiversity, refers to the variety of biotic components of an ecosystem, but is much more than simple counts of species and their relative abundances (Noss 1983; Hughes and Noss 1992). Measures of the rarity or the functioning of a species within the larger ecosystem context must be assessed as well. In addition, some conservation biologists include ecosystem processes as elements of biodiversity to be conserved under ecosystem management.

High-quality, naturally functioning ecosystems exhibit ecosystem health (J. Young) and biotic integrity (Karr 1993). Current practices in the medical field serve as useful, living-system metaphors to ecosystem health. A medical doctor takes certain, indicative measurements of a patient's system (body) in order to diagnose disease and prescribe a treatment. In ecosystem management, scientists take certain, indicative measurements of the system (ecosystem) in order to understand its current composition and function, and prescribe conservation measures to improve its condition. Unlike the situation in the field of medicine, in which most of the basic components

and functions of a patient's system are understood and diagnostic indicators have been defined, much ecosystem knowledge needs to be acquired. The proper indicative measures, or "indicators," for ecosystems are not yet clearly defined, nor are the ideal conditions toward which we wish to manage (J. Young). However, the metaphor provides a useful framework in which to develop the field of ecosystem management.

Biological integrity refers to a system's wholeness, including presence of all appropriate elements and occurrence of all processes at appropriate rates (Angermeier and Karr 1994). A system with biotic integrity is able to support and maintain a balanced, integrated community of well-adapted organisms comparable to the natural diversity of the region (Hughes and Noss 1992; see Regier 1993 for a long list of characteristics of an ecosystem with integrity). The existence of integrity implies that the system is healthy. Karr (1993) defines ecosystem health as the condition when a system's inherent potential is realized, its condition is stable, its capacity for self-repair is preserved, and minimal external support is needed. Costanza, Norton, and Haskell (1992) suggest that a healthy ecosystem is "stable and sustainable...it is active and maintains its organization and autonomy over time and is resilient to stress." Although the precise implications of these concepts are still under discussion (e.g., what is the meaning of "stable"), it is agreed that conserving biotic integrity will, by definition, conserve biodiversity and TES.

For the specific goal of TES conservation, ecosystem management requires strategies that not only provide for species-specific requirements, but also maintain or strengthen the relationships between TES and other organisms, and maintain or improve the physical environment in which the TES exist. Often, natural historical disturbance patterns are necessary to recreate or maintain the conditions in which TES evolved. Thus, change or disturbance (even if human-generated) in the ecosystem is acceptable, even desirable, as long as the ecosystem recovers its ecological and productive capacity (Franklin 1994). The inclusion of change and natural disturbance regimes makes ecosystem management a flexible tool for resource managers. Human activities that mimic natural disturbance and do not reduce biotic integrity or TES populations can be incorporated into conservation schemes.

Thus, ecosystem management has the potential to reconcile human use, such as natural resource extraction and military training, with conservation. To reconcile human use with conservation,

- the natural, historic disturbance regime should be followed and/or restored as much as possible,
- a landscape-level perspective should be established whenever planning land use activities or impacting the land directly,

- land uses should be matched to land capacities and natural system characteristics, but people should not divert all of the system's resources; much of the productivity should remain in the system to ensure its capacity for self-repair and resilience to stress,
- the natural world should be recognized as a complex living system, not a simplified source of commodities, and
- ecosystem managers should recognize that changing one element of an ecosystem can reverberate throughout the entire system, affecting other elements at multiple scales.

Interactions, relationships, and synergisms (sometimes called "cumulative effects") must be taken into account. If conducted properly, ecosystem management should enable the land manager to provide for broad natural resource needs while supporting the natural processes that sustain TES.

Although ecosystem management is still an emerging conceptual approach, its use will become customary in the future as land managers and researchers implement it. In fact, much progress has already been made in refining the principles of ecosystem management. The DOD has defined the following principles and guidelines for ecosystem management (Attachment to the DUSD[ES]/EQ-CO memo dated 08 Aug. 1994):

1. Maintain and improve the sustainability and native biological diversity of ecosystems. Recognize, restore and sustain the composition, structure and function of natural communities to ensure sustainability and biodiversity at all relevant scales.

2. Administer with consideration of ecological units and time frames. A larger geographic view and more appropriate ecological time frames should improve analysis of cumulative effects.

3. Support sustainable human activities. Actions should meet the needs of the present without compromising the ability of future generations to meet their own needs.

4. Develop a vision of ecosystem health. All interested parties will collaborate to develop a vision of desired future condition concerning ecosystem health and biodiversity.

5. Develop priorities and reconcile conflicts. Mechanisms should be designed to establish priorities among objectives and to resolve conflicts during both the selection of objectives and the methods for meeting objectives.

6. Develop coordinated approaches to work towards ecosystem health. Cooperation across ownership and political boundaries is an important component of ecosystem management.

7. Rely on the best science available. Management is based on scientific understanding of ecosystems.

8. Use benchmarks to monitor and evaluate outcomes. Implementation of ecosystem management should include specific, measurable objectives and criteria with which to evaluate activities. Accountability measurements are vital.

9. Use adaptive management. Management practices should be flexible to accommodate the evolution of scientific understanding of ecosystems.

10. Implement through installation plans and programs. The desired future condition of ecosystems should be achieved through linkages of DOD plans and activities.

Similarly, a review of conservation literature and documents from other Federal agencies identified the following characteristics of ecosystem management:

1. Strives to conserve biodiversity and biotic integrity, while defining precise component goals, (e.g., TES population goals, community composition goals) since the concept of "natural" is subjective (Johnson and Agee 1988).

2. Integrates goals and actions up and down geographic scales (Salwasser 1990).

3. Integrates goals and actions across the spectrum of biodiversity, which would include the composition, structure, and function of populations, species, communities, and ecosystems (Salwasser 1990; Noss 1991; Grumbine 1994).

4. Integrates ecological, economic, and social values into clear, practical objectives, and/or a "desired future condition," which may change through time (Biodiversity Task Force 1992; Quigley and MacDonald 1993; Grumbine 1994).

5. Emphasizes processes, not just organisms (The Keystone Center 1991; Pickett, Parker, and Fielder 1992; Samson 1992).

6. Adopts an anticipatory, preventative approach to avoid large population declines, instead of merely reacting to declines that have already occurred (La Roe 1993).

7. Recommends land uses consistent with the resiliency and limitations of the land, in order to sustain productivity and usefulness indefinitely (Samson 1992; Quigley and MacDonald 1993). Accommodates multiple uses at a regional scale, but allows management for a dominant use at individual sites (Agee and Johnson 1988).

8. Recognizes that a significant amount of productivity needs to be channeled to species other than humans in order to sustain complex linkages that are vital to the system (K. Jope).

9. Recognizes that variability and change are inherent properties of natural systems (Johnson and Agee 1988; Quigley and MacDonald 1993). Maintains and mimics natural ecosystem processes and structural diversity (Christensen 1988; Council on Environmental Quality (CEQ) 1993).

10. Maintains and/or enhances those landscape elements that are currently neglected in community classification schemes, such as gradients and mosaics (E. Grumbine 1990).

11. Requires common policies and objectives across jurisdictional boundaries in order to manage appropriate ecological units, such as ecosystems (Agee and Johnson 1988; Varley 1988; MacKenzie 1993; Grumbine 1994).

12. Integrates inventories, mapping, data bases, research and monitoring across disciplines, through adaptive management and regional cooperation (Agee and Johnson 1988; U.S. Department of Agriculture [USDA] 1992; Quigley and MacDonald 1993; U.S. Department of the Interior [USDI] 1993; Grumbine 1994).

13. Recognizes scientific uncertainty (Lubchenko et al. 1991; Solbrig 1991; CEQ 1993; Grumbine 1994), while requiring a working knowledge of the ecosystem (J. Young).

14. Recognizes humans as imbedded in nature. Humans strongly influence natural processes and, in turn, are influenced by them (Agee and Johnson 1988; Quigley and McDonald 1993; Grumbine 1994; K. Jope).

Grumbine (1994) isolated five specific goals for ecosystem management in his recent literature review:

1. Maintain viable populations of all native species in situ.

2. Represent, within protected areas, all native ecosystem types across their natural range of variation.

3. Maintain evolutionary and ecological processes, such as disturbance regimes, hydrologic processes, nutrient cycles, etc.

4. Manage over periods of time long enough to maintain the evolutionary potential of species and ecosystems.

5. Accommodate human use and occupancy within the above constraints. Although ecosystem management promises to incorporate human activities into naturally functioning ecosystems, a great deal of work is needed in this area. The older goal of providing goods and services to people must be reconciled with the newer goal of protecting ecosystem health and integrity. Current confusion about ecosystem management is largely driven by differences in philosophy and approach to this issue (Grumbine 1994).

Philosophically, ecosystem-based management incorporates respect for all components of the natural world, belief in a long-term investment horizon, and the humility to accept that humans will never understand the natural world enough to truly “manage” it (J. Young).

5 The Scientific Uncertainties and Technical Challenges of Ecosystem Management

The scientific uncertainties and technical challenges of ecosystem management have received thoughtful attention from conservation biologists. The overall technical challenge is (1) to acquire and synthesize data that describe complicated ecosystems, and (2) to generate and evaluate land use and management options across the landscape that maintain ecosystem processes and linkages. While implementing ecosystem management, the Army and individual installations face new hurdles. They include the following five steps (each of which is discussed in detail below):

1. Identify the appropriate land unit for planning and perspective. Ecosystem management plans would be designed for biologically relevant units of land, not artificial administrative units.

2. Complete inventories of the land unit to identify TES and other elements of the land unit. Elements would include plant community types and even ecosystem types, both of which would require standard, rigorous classification systems.

3. Prioritize the elements of biodiversity across the landscape, considering their functional importance within their ecosystems. Evaluate whether TES function as, or depend on other, keystone species. Determine the impacts of exotic species.

4. Plan a management strategy that reintroduces the historic natural disturbance regime, maintains ecosystem processes and linkages, promotes native species in their community context, and integrates human activities with historic landscape processes.

5. Establish a long-term adaptive management program to monitor conditions at all ecological levels (population, community, ecosystem, etc.). Indicators should not only reflect composition of the ecosystem, but also its structure and function. Indicators should represent the components, processes, and linkages of the system that are most likely to be impacted through land use.

The above elements of ecosystem management are interrelated. Decisions about or progress made on one will limit or simplify the options available for others. Even though each is discussed independently below, ecosystem managers need to consider them holistically.

Identify the Appropriate Planning Unit

Government agency land boundaries were designated through a political process without fully considering ecological processes. This makes it difficult for land managers to account for, prevent, or minimize damaging that frequently are generated outside their administrative boundaries. The resulting problems have inspired calls for "greater ecosystem" designations in several places, most notably in the Greater Yellowstone Area (Varley 1988). These efforts are really pressuring agencies to plan on a regional scale, based on biological and ecological linkages, not necessarily on easily-defined "ecosystem" boundaries. Consideration of ecological linkages and boundaries in resource management planning could enhance ecosystem function and biotic integrity.

Appropriate designation of units for planning and coordination is an important prerequisite to good ecosystem management. Management unit boundaries should (1) encompass ecosystem and population processes and patterns, and (2) include enough area to maintain compositional, structural, and functional stability through time (in the absence of catastrophic external impacts; Slocombe 1993). Designation of boundaries should consider historical disturbance regimes, community composition, physical features (Wilcove 1993), and species' needs and distribution patterns (R.E. Grumbine 1990). Since ecosystems do not have sharp, distinct boundaries, but rather have gradual transitions, distinguishing among them involves interpretation and judgement (La Roe 1993). Furthermore, ecosystems are constantly changing, and the various components within them may each have different boundaries, so that the system as a whole is really made up of overlapping sets of interrelated systems (Johnson and Agee 1988).

Nonetheless, some researchers have proposed rules by which to determine appropriate planning boundaries. Pickett and Thompson (1978) first discussed the scale of species dispersal abilities in relation to habitat patchiness. They assert that a reserve (or a management unit) should be circular, undivided or well-connected, and should encompass a "minimum dynamic area": the smallest area that can maintain a natural disturbance regime and internal recolonization sources.

Others have suggested using watershed or bioregional boundaries. For example, a management plan for an endangered plant and its entire alkali sink ecosystem was recently developed in California. Three land use zones were delineated. The first included existing and potential habitat for the resident endangered plant. The second included all designated wetlands. The third, least protected (but nonetheless managed) zone included the entire watershed contributing to the alkali sink (Coats, Showers, and Pavlik 1993). A bioregional approach would generally take into account social and cultural (land use) characteristics of the landscape more than a watershed approach. Unfortunately, we lack the information to consistently define watershed boundaries (since watersheds exist within watersheds) or bioregion boundaries. Often, the same ecosystem types occur in two adjacent watersheds. Should those watersheds have different management plans? We lack knowledge of the implications for planning and management once specific boundaries are chosen (Slocombe 1993). There is also controversy over how to balance land use, social, and/or political criteria with ecological criteria in the designation of a management unit. Slocombe (1993) feels that land use conflicts can be reduced by incorporating public opinion about the region into the process of determining a management unit.

One approach (that seems appropriate for TES conservation) is to manage the area needed to maintain a minimum viable population of the species (usually a top predator) that requires the largest home range (Craighead 1979; Noss and Harris 1986). This strategy would minimize problems similar to those near Yellowstone, where large ungulates and predators leave the park boundaries during normal home range or migratory movements and spark land use conflicts. Since this approach focuses on the needs of a single species, managers should remain aware of the requirements of other important ecosystem processes and linkages so they are not compromised in the process.

Many feel that management area delineation should consider the physical environment, not just the biotic composition. The physiography, soils, and topography of an area all combine to provide a template for flora and fauna to move across through time as the climate changes. Biodiversity is related to diversity in physical microhabitats. Therefore, many physical environments, especially if they support unique communities, should be included in each management unit (Hunter, Jacobson, and Webb 1988).

It is important to remember that (1) determining the land unit to be managed, (2) inventorying the biotic and abiotic elements of the region, and (3) prioritizing those elements for conservation, are all closely related and should all be done at the earliest stage of planning. In fact, when the Man and the Biosphere (MAB) program establishes a reserve, they begin with intensive inventories and prioritization of potential sites. They consider the spatial and temporal distributions of ecological

resources and processes, as well as human activities (Gilbert 1988; Ray and Gregg 1991). Then they choose a site and determine its boundaries.

It may be best to designate different management units for different management goals. For example, water pollution prevention may necessitate a watershed ecosystem designation, while the conservation of a TES would necessitate a management unit based on distribution of habitats.

In summary, ecosystem management should be implemented on an ecologically relevant land unit, upon which (1) historical, natural disturbance regimes occur, (2) habitat heterogeneity is maintained in diverse physical environments, and (3) native populations can shift and recolonize across the landscape as environmental conditions change.

Inventory With a Rigorous Classification System

It is important to have a thorough inventory of all biological resources and an understanding of the natural ecological processes in order to designate a management unit, reintroduce natural processes, or support TES conservation. In fact the only way to make holistic decisions on a landscape scale is to be familiar with the natural ecosystems within the landscape.

The inventory should gather the following information (taken from O'Connell and Noss 1992):

1. The abundance and distribution of flora and fauna (including community and possibly even ecosystem types, all of which are referred to as "elements of biodiversity"), and the most significant, known interactions and dependencies.

2. Soil, geology, and hydrology, and the erodibility of the soils and consequential effects on flora and fauna.

3. Types, locations, and intensities of land use on site, and their effects on flora and fauna.

4. Present and potential influences from the surrounding land uses.

5. Evaluation of natural disturbance regimes.

6. Assessment of the value of biodiversity elements in a regional and global context (e.g., Is this a rare plant community found on an unusual type of soil? Does this species function as a keystone species?).

7. Ecological history of the site, including past disturbances and their effects on current plant and animal distributions.

8. An assessment of how the ecosystems respond to different types of stress (Lubchenko, et al. 1991).

Some of this information can be acquired from aerial photos, satellite imagery, maps, old survey records, the Natural Heritage Inventory database, installation records, other government agency records, and local sources. In Michigan, aerial photos have proven effective for identifying habitat, potential habitat, and changes in habitat (Dr. David Ewert, Director of Science and Stewardship, Michigan Nature Conservancy, professional discussion). A balance must be struck between detailed data, which provides a great deal of information for site managers, and broad data, which facilitates coordination among multiple landowners who are managing their lands cooperatively. Most likely, both types of data will be required (D. Ewert); managers will have to identify the critical data needs at both scales.

Natural disturbances, processes, interactions, and influences differ among regions, and must be identified on a regional basis, without a formal system of classification. In contrast, identification of ecological communities and ecosystems has been promoted by efforts to develop a scientifically sound, generally accepted classification system for entities that have variable characteristics in space and through time (often called "community types" and "ecosystem types"; Noss 1987a). Emphasis on the community or ecosystem provides a context for management of species and provides information about landscape composition.

A suitable community classification system must provide clear criteria for identifying the ecological communities found all across the United States, although a different classification guide would probably be produced for each region. The system must have the power to predict the association between communities and their physical environment. It also must correspond to species ranges in such a way that protection of all community types will adequately protect biodiversity (Bourgeron 1988; Orians 1993).

A basic characteristic of classification systems is the type of information included. Historically, botanical classifications have been based on vegetation. The Nature Conservancy has taken a leading role in developing classification systems for

conservation purposes (Noss 1987a). TNC is developing a community classification that will be consistent throughout the United States at appropriate scales for conservation planning, and for the management and long-term monitoring of ecological communities and ecosystems (TNC 1994). In this emerging system, vegetation, both natural and seminatural, is the primary attribute used to classify terrestrial communities, but the system also recognizes "cultural" land cover, such as crops, lawns, concrete, and buildings. The classification uses existing vegetation, instead of potential vegetation, which provides the level of detail required for inventory and site description, and is useful for landscape modeling. In the field, community types are recognized as structurally and vegetatively homogenous stands that occur in a relatively uniform environment, however, environmental variation occurs within each community type across environmental gradients and the landscape. TNC's system assumes that vegetation is the best and most easily measured assimilator of complex environmental and historical site conditions - so while the classification system is defined by vegetation only, the concept of vegetational community captures environmental and other biotic information as well. Because of this, TNC recognizes geologic setting, insect fauna, and disturbance history within each community description (TNC 1994).

In contrast, classification systems have been developed that combine vegetation data with environmental, abiotic data. The underlying relationship between the abiotic environment and the existing or potential vegetation is determined through gradient analysis, then the results are summarized through the process of classification (Gauch 1982). In direct gradient analysis, major environmental variables that are known to affect plant response are ordered along n axes. The location of each species with respect to those variables are drawn in n dimensions. Relationships can be summarized by subjectively drawing boundaries between communities (e.g., DeVelice, DeVelice, and Park 1988) or by using various statistical techniques (Gauch 1982). This classification method helps identify all physical/ biotic combinations and forms community designations based on response to the environment. For these reasons, some feel it is more appropriate for ecosystem management than systems that rely solely on vegetative parameters (Christensen 1988; DeVelice, DeVelice, and Park 1988). Physical factors provide a "broadly relevant basis" for classification, unlike dominant plant species, which may or may not consistently reflect the species composition of the entire community. Although biotic components will remain important, classification systems that incorporate biologically relevant thresholds among physical gradients are preferable (Hunter 1991).

In recent years, an ecological site classification system, incorporating both vegetation and abiotic data, was developed by the Forest Service in Michigan for integrated resource planning and management, including the conservation of biodiversity

(Cleland et al. 1993). Upper levels of the hierarchical classification follow previously proposed categories based on climate and physiography (Bailey 1987). Divisions are made according to existing regional classifications, but are augmented with site-specific data. Lower levels are determined by local geomorphology, climate gradients, soils, physiography, and vegetation (Host et al. 1993). Field ecologists catalogue physiography, soil, and vegetation along topographic gradients using transects and sample plots. Any recurring, homogenous set of these characteristics is called a "mappable" ecosystem type. When mapping is performed, boundaries are examined in the field to ensure accuracy. Once the ecosystem types are identified, they are refined or revised according to "ecological species groups," which are identified by correlating moisture, drainage, nutrient, soil reaction, and light intensity gradients with ground cover plant community composition. Often a suite of species is tightly associated with certain physical characteristics. The presence of those ecological species groups are then used to indicate those correlated conditions and the data is integrated into ecosystem definitions. This system of identifying ecosystem types has successfully predicted Kirtland's warbler abundances and colonization patterns (Barnes 1993).

An entirely new landscape classification system identifies functional groups of relatively persistent community types across the landscape (Noss 1987a). The system mimics the structure of older community classification systems; just as species are combined into traditional community types, combinations of community types are combined into landscape types. Disturbance events, frequency, intensity, size, and predictability are evaluated for each landscape type as well. Development of quantitative indexes to describe landscape structure has already begun (reviewed in Turner 1989); additional, similar research would be important for complete development of a landscape classification system.

In summary, ecosystem management planning will be optimized when managers have (1) a complete inventory of the site's biotic and abiotic resources, (2) an understanding of the natural disturbance regime on the landscape, and how it influences population, community and landscape characteristics, and (3) data on the physical characteristics and land uses on site and on the surrounding landscape, and how they influence species, populations, and processes such as disturbance regimes. To gather this data in an organized manner, managers can use a standardized classification system of community types, ecosystem types and/or landscape types.

Prioritize the Elements of Biodiversity

Once managers know what species, communities, and ecosystems are found on their management unit, they must focus on a limited number of those elements to streamline and simplify management planning, analysis, and decisionmaking. It is important to choose focal elements carefully, since management of the entire ecosystem will be based on those selected factors. Selection should be guided by the goals of ecosystem management. For example, focal elements may be chosen because they maintain or improve biotic integrity. For the purpose of TES conservation, land managers may identify those elements of the ecosystem and landscape that are essential for the conservation of TES, and manage accordingly. The focal elements might be populations, species, or they might be on a larger scale. Distinct biological communities or ecosystems that are unique or sensitive, such as forest interior birds or selected stages of successional forest could serve as foci of management (Salwasser 1990).

Importance of Structure and Function

Ecosystems have three main attributes: composition, structure, and function (Franklin 1988). Although inventories focus on the first characteristic, Hansen and others (1991) provide a useful example of how to evaluate all three traits at the community or ecosystem scale. Researchers initially studied differences in stand structure in natural Douglas fir forests. That effort included a literature search on natural rates of disturbance for the ecosystem. Natural stands of different age classes were compared for age structure, abundance of understory plants, volume of downed wood, and snag abundance. Their results revealed different structural features in old-growth stands compared to younger stands. Field data combined with an understanding of natural disturbance demonstrated that natural disturbances, such as fires and windthrows, maintain a relatively complex structure even in young stands. In related studies, native plant and vertebrate species richness, species diversity, total abundances, and community overlap were also compared among different aged natural stands. Little difference was found among young, mature, and old-growth forests.

This contrasts with findings in managed forest communities. Researchers also compared managed forest plantations with natural forests in terms of species composition, structure, and the ability to support biodiversity. To assess the effects of logging, previously clearcut and previously uncut plantation stands (which also covaried with respect to age) were compared for densities of large trees and snags. Results in this study indicated that clear-cutting substantially reduced structural complexity. Mapping projects examined the loss of interior habitat over the landscape. The data verify that the effects of habitat fragmentation are substantial even where

cutting units make up less than 20 percent of the landscape. Bird, reptile, and amphibian abundances were correlated with stand size and proximity to clearcuts. Although further work is needed to compare animal species richness and abundance in younger plantations vs. older natural forests, the limited data available show reduced numbers in animal communities in young managed forests (Hansen, et al. 1991).

These research projects reflect the work of many scientists over many years. However, such data begin to reveal the functional qualities of different ecosystem components with respect to TES or biodiversity in general. As our understanding of ecosystem dynamics grows, we can better identify and prioritize the focal elements of management plans.

Communities and Habitats as Focal Elements

Vegetation communities and specific habitat types can function as focal elements for ecosystem management, especially if they are critical to TES or promote biodiversity. Focusing at the community level, will support multiple species more efficiently than a single-species approach. Since limited resources may not allow management or protection of every last remnant of a community or habitat type, managers need strategies for choosing areas for protection.

A protocol for establishing priorities for protection of coastal plain plant communities was developed recently in Ontario, Canada (Keddy and Sharp 1994). The focal element of interest is the plant community and the objective is to identify which sites (in this case, lakes) should receive protection. In the first phase of the process, site significance was determined by the formula: 4(# coastal plain plant species) + 3(# rare coastal plain plant species) + 2(# coastal plain plant species considered rare in Ontario) + (# other rare species). The multiplication ensures that factors are weighted according to their perceived importance. Managers considered the total number of coastal plain plant species more important than number of rare coastal plain species, which in turn was considered more important than number of other rare species. Through this initial calculation, a group of 12 sites was ranked much higher than the remaining sites. Then those 12 sites' ranks were adjusted to 2 more criteria: (1) the relative population sizes of individual species, and (2) the relative length of shoreline supporting those coastal plain species. The degree of threat to those coastal plain communities was also assessed, and incorporated subjectively (Keddy and Sharp 1994). This protocol may serve as a useful guide for prioritizing sites for conservation based on community composition.

For similar reasons, but using vastly different data and methodology, priorities can be set on a regional basis to identify areas of great biological value (e.g., high quality habitats) that lack protection. Gap analysis (Scott, et al. 1987; Scott, et al. 1991) is a geographic information system (GIS) analysis that includes data on (1) existing vegetation types, (2) physiographic characteristics, (3) vertebrate distribution centers of species richness and centers of endemism for each vegetation type, (4) invertebrate (usually butterfly) distribution centers of richness and endemism within each vegetation type, (5) TES distribution, and (6) areas managed for the preservation of biodiversity, along with an assessment of the degree of protection. Although these distributions can be determined by maps, vegetation and animal distributions should be verified with fieldwork. Centers of richness are compared to minimize redundancy and then ranked according to their contribution to local, regional, and global biodiversity. The crux of gap analysis is a comparison of data layers on unique, sensitive, or highly diverse areas to data layers on protected areas. In this way, "gaps" in regional conservation efforts become clear and can be given priority in any conservation efforts.

Species as Focal Elements

In the context of TES management, it is logical to use TES as focal elements in developing management priorities for ecosystem management. Most conservation biologists consider a species approach (consideration of the needs of one species) and an ecosystem approach (consideration of ecosystem characteristics, such as structural complexity) to be complementary.

There are five overlapping classes of species that have been suggested for prioritizing conservation efforts. To varying degrees and to an unknown extent, protecting these species will help maintain the entire ecosystem. The five classes are (Noss 1991):

1. Indicator species. These species indicate the presence or absence of a certain requirement or stressor in the environment. For example, the presence of certain sedges in wetland ecosystems indicates a stable hydrology of wet, but not inundated, soil. The selection of indicator species is critically important, since a poor choice may harm conservation efforts. A multifaceted suite of indicators chosen by biologists familiar with the region is most effective.

2. Keystone species. Species that play a pivotal role in the maintenance of community composition and ecosystem function are called keystone species. For example, top predators control populations of intermediate predators (e.g., raccoons, opossums) that otherwise decimate songbird populations. However, the concept is poorly defined and broadly applied far beyond its original use (Mills,

Soule, and Doak 1993). Very little research has counted the number of species in a community with strong interactions; it may be a large number. Furthermore, the role of a species is specific to a particular environmental setting and community assemblage, and thus the concept is not generalizable enough to be used broadly in policy or planning guidelines (Mills, Soule, and Doak 1993).

3. Umbrella species. An umbrella species has large area requirements for home ranges. If they are provided with sufficient habitat, hundreds or thousands of other species will also have adequate habitat. An example is grizzly bears in the Greater Yellowstone Ecosystem.

4. Flagship species. Flagship species are charismatic animals, for the most part, that facilitate public education about and support for biodiversity issues. Examples include the bald eagle and the great whales, which inspired public education campaigns that led to greater environmental awareness.

5. Vulnerable species. Vulnerable species are particularly sensitive to human activities. Many ecological characteristics have been correlated with their status. Examples include the marbled murrelet in the Pacific Northwest, and the purple gentian, a prairie forb.

A somewhat controversial approach to species-level focal elements examines the amount of redundancy within the ecosystem and places a higher value on those species that perform functions that no others perform. Walker (1992) suggests guild analysis to develop functional classifications of the biota. An iterative process can be used to subdivide each group on the basis of important ecosystem-function attributes. The number of species in each group will show the level of redundancy for each function; those groups with fewer species should receive higher priority. Further study can examine the interactions within each group and the relative importance of each group through selective removal experiments (Walker 1992). This strategy requires much time and research effort to accumulate enough data to make sound decisions. Even then, the data may represent only the particular system studied for a limited amount of time. Much past experience contraindicates this approach, since we don't know how species really function within ecosystems, how to measure costs to the ecosystem of species losses, nor over what time span these costs may accumulate. Experiments with substituting various components within ecosystems have been quite damaging (reviewed in Ehrlich and Mooney 1983). In general, all approaches that focus on individual species alone risk losing sight of the multitude of other components and linkages in the ecosystem as a whole.

In summary, by carefully assessing the goals of ecosystem management, appropriate focal elements can be identified at the community, habitat, or even species level that facilitate planning and analysis.

Manage the Landscape for TES Conservation

All of the previously listed principles of ecosystem management play important roles in developing an ecosystem-based management plan. The hallmark of a good plan is its holistic and long-term perspective. One aspect of ecosystem management is the conservation of biological, physical, and functional heterogeneity across landscapes and through time. The challenge of ecosystem management planning is to first describe the optimal condition and use of the land and then to implement changes at the landscape level that (1) integrate human uses with landscape processes, and (2) promote native species, such that the optimal condition is created and maintained.

Desired Future Condition

The optimal condition of a landscape is often called the "desired future condition." It is determined through a political process that accounts for local culture, natural processes, and land use (D. Ewert). It provides a vision of what the landscape will look like and how ecosystems will function under a successful plan. For example, the Mississippi River Alluvial Plain Project of The Nature Conservancy describes the optimal condition of any land unit as being part of a large forested tract on which natural disturbances create a shifting mosaic of relatively even-aged patches of relatively small size. The mosaic should include a great variety of stand ages (Pashley and Creasman 1993). This vision may be appropriate for the Mississippi River alluvial plain, but may be entirely inappropriate for other ecosystems.

Pre-European settlement conditions often are used as a reference point for the desired future condition (Biodiversity Task Force 1992; Samson 1992). This criterion makes political and social sense, and provides a known basis for monitoring land use impacts (Ralph Costa, Red-cockaded Woodpecker Recovery Coordinator, Southeast Region, Fish and Wildlife Service, professional discussion, 27 June 1994). Pre-European settlement landscapes represent the environment to which most TES are adapted as well, so it makes ecological sense to restore similar landscapes in support of TES conservation.

How should natural change be included in the desired future condition? Since ecosystems are constantly changing and variation in disturbance regimes, environmental conditions, and species distributions affects the structure and function of the

ecosystems, managers must determine what kind of change is acceptable and what kind of change is not. For example, it is legitimate to debate whether maintenance of every species at a given site is necessary. If not, at what time scale and in what way will changes in composition be acceptable (Landres 1992)? Since one ecosystem management goal is to conserve TES, some decisions will be dictated according to compliance requirements of the ESA. However, ecosystem-based management considers the multitude of other species and processes in the system as well. Choices about species maintenance, community composition, disturbance regimes, and other ecosystem components will be necessary. Those decisions, and the resulting definition of "desired future condition" should be based on the best scientific knowledge, expert opinion, and social priorities. As part of the natural systems, humans are forced to acknowledge the impacts of those decisions.

Effects of Human Activities

Of course, the most difficult decisions involve human activities and their impacts at the landscape level. Many conservation biologists feel that ecosystem management provides a strategy for integrating human use of natural areas and natural values such as TES conservation (Noss 1991; Salwasser 1991). By conserving natural processes and redundant components such as species, ecosystem management will maintain the resilience of ecosystems (with respect to composition, structure, and function). Resilience allows ecosystems to respond to human-induced impacts as well as to natural fluctuations, thereby minimizing the ecosystem and landscape-level effects of human activities and the consequent impacts on TES.

Human activities are known to rescale natural patterns and processes in both time and space, which can negatively impact native species. Human activities:

- rescale patch dynamics, which can reduce the effectiveness of species' adaptive traits,
- rescale habitat edges, which can destabilize community interactions,
- introduce novel patches, species, and dynamics, which hampers the evolution and effectiveness of adaptive traits, and
- homogenize landscape patterns, which reduces habitat availability and diversity (Urban, O'Neill, and Shugart 1987).

These negative impacts should be minimized, and natural patterns and disturbances should be encouraged and reintroduced. If an area is not large enough to incorporate natural disturbance patterns, some disturbances may be induced at smaller spatial scales in order to encourage a landscape equilibrium (Urban, O'Neill, and Shugart 1987).

Relationship Between the Species Level and the Landscape Level

Since ecosystems exist at all scales and have overlapping, interactive properties, viewing landscape components in a hierarchical manner makes their relationships clearer. Events occurring at a low level (individual level or species level) tend to be frequent and small in size, i.e., a single treefall. Several of these events will exist within the context of larger, slower events (perhaps within a patch of forest), which in turn lie within a broader grassland/forest mosaic (at the landscape level). Events at higher levels tend to be larger and less frequent than those at lower levels. At each hierarchical level, an event will have its mechanistic explanation at the next lower level, while the significance of the event will be understood only in the context of the next higher level (Urban, O'Neill, and Shugart 1987). Because of these relationships across scale, species are affected by landscape processes, and vice versa.

These relationships also mean that landscape-level planning and management actions can be used to conserve TES. A large-scale example is the conservation strategy developed for the Northern Spotted Owl in the Pacific Northwest (Thomas, et al. 1990). All management objectives were explained in discussions of the relevant ecological and conservation principles. The links between population requirements of the owl and recommendations for a landscape-level habitat mosaic were made clear. It was a comprehensive example of a plan to manage an entire regional ecosystem based on the requirements of one species (Salwasser 1988). However, we cannot simply mimic that approach in all situations. The U.S. Forest Service (USFS) management goal for that plan was to conserve one species, and that may be a dangerously simplistic and inefficient way to approach ecosystem management. The initial conservation strategy has now been superseded by the Northwest Forest Plan, which strives to conserve the 8,000 species that are associated with the northern spotted owl habitat (K. Jope). The needs of many associated species, including marbled murrelets and Pacific salmon, were not adequately addressed in the initial conservation strategy for the owl. Similarly, in the southeastern United States, Army guidelines for management of the endangered Red-Cockaded Woodpecker currently have been re-evaluated for their impacts on other species in the region (Jordan, Wheaton, and Weiher, draft). The challenge is to evaluate TES requirements with a landscape perspective, as did the USFS, while also considering a wider range of ecosystem components. Consideration of multiple TES provides the efficiency and effectiveness that has made ecosystem management popular among Federal land managers, politicians, and conservationists alike. Thus, landscape-level, process-oriented planning balanced with the requirements for focal elements of biodiversity should result in the most effective management plan.

However, not all options for managing the landscape for biodiversity (much less for ecosystem or biotic integrity) are clearly understood. For example, when using

landscape-level management to conserve TES, the relationship between habitat patterns and scale must be carefully assessed. Although certain practices may increase diversity locally, they may decrease diversity across a region. For example, as edge is increased, local species richness may increase, but it will mainly be due to the addition of edge species, which are generally common in urban or agricultural landscapes. Sensitive species, such as neotropical migrants, forest interior species, rare, or endemic species, which are often TES, will likely be lost over the entire landscape, decreasing overall diversity and homogenizing the biota (Noss 1983; Temple and Cary 1988). The degree to which this occurs may be landscape-specific (Martin 1992). To minimize the homogenization of flora and fauna, Knopf (1992) recommends that biodiversity be highest at the national scale, then regionally, and lowest at the local scale. Management practices should optimize (not necessarily maximize) species richness on specific sites while emphasizing between-habitat diversity (Noss 1983). In other words, each site would be managed to reflect its natural biota, nothing more, nothing less.

Because of our poor understanding of landscape processes, planning for ecosystem management of TES will require continual management-based research of natural processes; results from one region may not be applicable to other areas. Managers and researchers need to identify the relationships among life histories, population viabilities, and landscape issues as they relate to TES of concern. For example, the probability of having suitable microhabitat in a given area will differ across the landscape, leading to variations in the minimum area requirements for each species. Thus population viability and carrying capacity may vary across the species' range (Martin 1992). Research is needed to identify:

1. the specific habitat needs of sensitive species,
2. the underlying causes of population declines,
3. the effects of fragmentation in a variety of landscapes,
4. the life history characteristics that affect vulnerability to human-made disturbances (Martin 1992),
5. the stage of life most critical to survival and reproduction (Schemske et al. 1994), and
6. the abundance and distribution of potential habitat.

As new data are accumulated, management strategies can be adjusted.

Distribution of Habitat on the Landscape

Ecosystem management planning attempts to protect and enhance TES habitat while minimizing land use conflicts. The most widely-discussed habitat requirement for

long-term TES conservation is the connectedness of habitat across the landscape. There is debate about the level of connectivity required for conservation purposes. Current research examines both the amount of connectedness required, and the characteristics (e.g., patterning, quality) of the habitat connections. One computer model simulation predicted that any habitat has a "connectivity" threshold: when randomly distributed, habitat must cover at least 60 percent of the land area for all organisms to perceive the habitat as one resource (high quality). When habitat is less common, pattern and scale (e.g., habitat fragmentation) become increasingly important characteristics of the quality of the habitat for animals (Pearson, et al. 1992).

Fragmentation of natural landscapes is a phenomenon with a multitude of biotic and abiotic effects at many scales (Saunders, Hobbs, and Margules 1991; Harris and Silva-Lopez 1992). When habitat is fragmented, plant and animal assemblages are affected through altered competition, and changes in predation, parasitism, and herbivory patterns (Harris and Silva-Lopez 1992). In addition, populations can become isolated; if one subpopulation disappears, migrating individuals are unable to reach it and recolonize it. Microclimates can be altered through changes in radiation and water fluxes, as well as increased wind effects (Saunders, Hobbs, and Margules 1991). When the area of suitable habitat is fragmented to the degree that it begins to function as an "island," genetic and demographic factors combine to reduce long-term viability of populations (MacArthur and Wilson 1967; Gilpin and Soule 1986; Charlesworth and Charlesworth 1987; Barrett and Kohn 1991). Losses of native species lead to simplification of biotic communities until they are dominated by generalist species. This process is a common cause of the population declines that lead to species' threatened and endangered status. Thus, fragmentation is identified as a critical problem that ecosystem management must minimize in order to support healthy populations.

The most common recommendation for reducing the effects of fragmentation is to increase habitat connectivity across a landscape via habitat corridors that link patches or reserves large enough to support the species of interest (Wilson and Willis 1975; Harris 1984; Noss 1987b; McEuen 1993). Some researchers are concerned that indiscriminate use of corridors will enhance the spread of catastrophic events (fire, disease, introduced predators), and exotic species. Furthermore, animals traveling within corridors are potentially much closer to human influences such as feral predators, poachers, or disease spread by domesticated animals (Simberloff and Cox 1987; Knopf 1992). Nonetheless, there is general agreement that corridors represent a partial solution to the complex problem of fragmentation (McEuen 1993). Their use should be monitored to evaluate their effectiveness.

Corridors should be designed based on the aforementioned focal elements/species, since the optimal size, width, shape, composition, and position within the landscape will probably be situation-specific. For example, mammals may use corridors more successfully if corridors are at least the width of one home-range, unless the corridor is so short that the animal does not need to feed while traversing it (Harrison 1992). However, if a corridor is wide enough to support survival and reproduction, it may serve as a reserve, and rate of movement through the corridor could be slow. The desired result will depend on the species of interest and the conservation goals (McEuen 1993). The following additional ecological research is needed to enhance the success of conservation via corridors (Harrison 1992):

1. Monitor how animals disperse with respect to topographic features and conspecific territories,
2. Investigate the cues used to determine dispersal direction,
3. Investigate mortality and movement patterns in nonsuitable habitat,
4. Identify and monitor natural corridors; for example, do not assume that areas are used as corridors without validation,
5. Determine the corridor width required for various species, and
6. Quantify the impacts of human influence as a function of distance from roads and other developed areas.

Besides providing connected habitat for TES, managers can accommodate TES by manipulating the way in which land uses impact natural systems. The most common recommendation is to mimic natural disturbance regimes (in accordance with current scientific knowledge) when any impact is necessary. There should be an effort to maintain the natural levels of heterogeneity and connectivity. When a certain level of habitat destruction is unavoidable and fragmentation is very damaging, connectivity in the remaining habitat can be encouraged by imposing contiguous habitat destruction instead of dispersing it throughout a natural area and causing fragmentation (Pearson, et al. 1992). If the natural disturbance regime produces small patches of disturbance, then this may not hold true. In either case, areas that are high quality habitat or marginally high quality habitat should be spared from destruction and/or restored to a healthier state. The distribution of various land uses and management schemes can be critical to ecosystem function and to TES population viability. Decisions about land use across the landscape should be carefully considered, with much input from ecologists and regional experts.

Landscape Strategies for Conservation

Ecosystem management emphasizes landscape-level solutions to landscape-level habitat alteration. Thus, an ecosystem management plan will prescribe the

reintroduction of natural processes and habitat patterns across the landscape, coupled with sustainable patterns of land use. One method for arranging land use according to its carrying capacity has been proposed by Hunter (the "triad" model; Hunter and DeMagnadier 1994). Currently, land use can be divided into three categories: (1) intensively managed and harvested/used systems, (2) unmanipulated, unharvested systems, and (3) "multiple use" systems, as defined by USFS, where the landscape is subjected to low-to-moderate levels of manipulation and harvest/use. In Hunter's forestry examples, land use is predominantly in the third category. His approach is to remove some of the land from multiple use management and intensively manage the most durable, fertile, accessible land in the most efficient way possible. This would leave the remaining areas available for conservation as natural systems, predominantly for TES, biodiversity, watershed, and ecosystem integrity. The level of production/land use is not sacrificed nor reduced in this scenario. It is rearranged in such a way that more land is available for ecosystem conservation. This model has potential problems. The most fertile and accessible areas may also be critical natural areas. In any case, intensive land use must still be incorporated in a sustainable manner, or it will affect the lands nearby that are managed for different values. This may not always be a viable model, but it illustrates the need to plan and manage on the landscape scale.

While the triad model arranges land use according to production needs, the "biosphere reserve" concept (Ray and Gregg 1991) first creates central core reserve areas, in which the highest quality natural habitat is found. The reserve areas then are surrounded by concentric zones of increasingly intense land use. Often, the entire biosphere reserve covers a large geographic region; the Carolinian-South Atlantic Biosphere Reserve consists of clusters of administrative units scattered over three states (Ray and Gregg 1991) while the MAB project in the southern Appalachians spans five states with five core reserve units (H. Hinote, Executive Director, Southern Appalachian Man and the Biosphere Project [SAMAB], professional discussion). The overall goal is to influence regional land use patterns and landscape processes for conservation purposes while simultaneously allowing land use activities. The best way to accomplish this is to create an entire landscape where ecosystem integrity is promoted, instead of destroyed.

In summary, the requirements of ecosystem focal elements and the historic, natural landscape characteristics such as disturbance and connectivity help describe the desired future condition of the land. Land managers can then control human impacts and land use decisions to mimic natural systems and live within natural systems as much as possible while still providing for human needs.

Establish a Monitoring Program

Unfortunately, ecosystem management is and always will be initiated and implemented without thorough understanding of every species, process, or interaction on site. It should be approached as a learning, experimental process. Land managers will never have perfect data with which to develop plans. By recognizing this explicitly, managers can establish a decisionmaking process that incorporates the opportunity to learn. Necessary decisions can be made, but knowledge can be gained in the process. It begins with identification of the desired future condition of the ecosystem and quantitative standards of success (objectives) early in the planning process, and then development of a monitoring program to evaluate the success of the management plan in reaching those objectives. The entire plan and monitoring program can be developed as a large experiment, or it can be done on a smaller scale, complete with an appropriate experimental design and stringent sampling program, in a process called "adaptive management." While management actions are based on current understanding of ecosystem processes, all assumptions and predictions should be explicitly stated, so errors can be identified as knowledge improves. Management actions then serve as experimental treatments, while the status of various "indicators" are the quantitative variables monitored.

Indicators play an important role as measurable, relatively clear parameters of the ecosystem that provide information about the status of the relatively fuzzy goals (referring to characteristics of community structure or biotic integrity, for example) of the management plan (Noss 1990; Williams and Marcot 1991). For example, to preserve regional biodiversity and biotic integrity in a tall-grass prairie (goals), managers may need to maintain a fixed ratio of native forbs to native grasses (desired future condition). They consult with experts and determine a specific desired ratio (i.e., 80:20, 60:40) for each of the next 15 years (objectives). They plan and implement a burning cycle of once a year for 5 years and then once every 2 years for 10 years (management plan actions). Every year, they randomly select an appropriate number of plots within the prairie, and calculate grass species, forb species, grass biomass, and forb biomass (indicators). Management actions are evaluated and modified according to the relative abundances of native grasses and forbs in the ecosystem (adaptive management). This whole approach is recognized as an important feature of ecosystem management.

The process of translating goals into a desired future condition is the first step. Then objectives and indicators must be identified. This stage of the monitoring program is critical to its overall success. For some, the metaphor of human health can be useful at this point (J. Young). Just as medical doctors have a rigorous definition of a normal, healthy human body, so must ecologists and managers develop a set of rigorous

criteria by which the condition (or "health") of the ecosystem can be judged. Once we understand what the optimal, desired, "healthy" condition is, we can pinpoint certain characteristics, or indicators, that will assist monitoring efforts. The chosen indicators will be the ecological analogies of human body temperature, pulse, respiration rate, reflex action, blood chemistry, etc. Clearly, if appropriate objectives and indicators are not chosen, the entire effort will suffer.

The concept of biological indicators for monitoring natural resources is well-established, but in the past, implementation has been flawed. Usually a metric such as the abundance of a species or group of species is used to assess natural resource conditions for environmental toxicology, pollution control, forestry, or range management issues (Noss 1990). This approach has been criticized for being too simplistic, both in its identification of the factors responsible for environmental degradation, and in its treatment of the components of biotic diversity (Hughes and Noss 1992; Karr 1993). Similarly, the use of vertebrate population status to indicate population levels of other species or habitat condition is not supported theoretically or empirically (Landres, Verner, and Thomas 1988). Indicators used in ecosystem management should represent compositional, structural, and functional ecosystem characteristics. To support a goal of TES conservation, the population, reproductive and distribution targets can be chosen as indicators through consultation with species experts or through Population Viability Analysis (PVA), but other aspects of the ecosystem should also be monitored.

An ideal indicator would:

1. be hypersensitive to stress in order to act as an early warning signal,
2. be widely distributed,
3. provide feedback across a continuum of stress intensities,
4. not require unmanageable sample sizes,
5. be easy to measure, collect, etc.,
6. allow managers to distinguish between natural variation and anthropogenic or unacceptable change, and
7. give managers information about critical ecosystem processes (adapted from Henderson, Noss, and Ross 1990; Noss 1990).

Landres, Verner, and Thomas (1988) recommend the following criteria for choosing indicators:

- predictable responses to environmental factors of interest,
- sensitivity to relevant environmental conditions (respond to small changes rapidly),

- applicability to scale of disturbance of interest (for example, species with shorter or longer lifespans may be appropriate), and
- year-round residency status, except for the monitoring of target winter residents or breeding species. Managers must keep in mind that an indicator suitable for one region may be inappropriate in another (Landres, Verner, and Thomas 1988).

No ecosystem element qualifies as a perfect indicator, so a combination of indicators should be selected according to the focal elements being monitored, management goals and objectives, the level of organization of interest, and ecosystem-specific characteristics. If biodiversity is viewed as a hierarchical construct, the monitoring program should be designed at multiple spatial and temporal scales (Noss 1990). Noss (1990) has developed a comprehensive table of possible indicator variables, organized according to level of organization (regional/landscape, community/ecosystem, population/species and genetic), and whether the variable is a compositional, structural, or functional component. A well-designed monitoring program should assess variables from all categories in order to truly represent the condition of the ecosystem of interest.

For example, the ecosystem management strategy for the Blue Mountains of the Pacific Northwest uses nine elements within the following categories as indicators: percent land in each successional stage, percent land in each plant community, density/vigor of lodgepole and ponderosa pine, amount of litter, and riparian conditions (Quigley and MacDonald 1993). These indicators provide information about landscape structure and dynamics, community composition, population viability, nutrient cycling, erosional processes, and habitat quality for both terrestrial and aquatic species. Similarly, the Klamath National Forest considers quantitative measures that represent vegetation and habitat types; species, community, and genetic diversity; stand structure; landscape (patch) patterns; linkages; connectivity; habitat turnover; nutrient cycling; fish habitat; and land use (Williams and Marcot 1991). The varying character of the indicators demonstrates the wide range of scales and processes considered in the respective management plans. Despite efforts to constantly improve knowledge about ecosystems and land use impacts, indicator selection criteria and assumptions should be explicitly outlined so that interpretation of results does not go beyond ecological reality (Landres, Verner, and Thomas 1988).

Karr (1993) divides biotic integrity into two major categories: elements (genes, populations, ecosystems, etc.) and processes (nutrient cycling, competition, etc.). He developed an multivariate Index of Biotic Integrity (IBI; Karr 1990, 1993) to monitor fish assemblages in Midwestern streams, and it is being modified for use throughout North America (Hughes and Noss 1992). The IBI is divided into three major classes of biological attributes, which are scored according to how closely they resemble

natural sites: (1) the abundance of certain elements, (2) food chain processes, and (3) overall population sizes and conditions of individuals. Each measure has a known relationship to anthropogenic disturbance, based on research results.

If the Army managed TES through ecosystem management, certainly some of the chosen indicators would assess the population status of those TES species. However, management would be greatly enhanced by adding several other indicators that represent additional scales or processes that are related to focal elements and management objectives, using systems such as those proposed by Noss (1990) or Karr (1990, 1993).

Once a suite of indicators has been selected, managers should formally describe the land's "baseline condition," to allow for comparison to the desired future condition and future changes in the landscape. To do this, current habitat, land use, and identified stressors (or sources of impact), should be mapped and compared to the desired future condition. Next, managers should formulate specific questions, related to management objectives, to be answered throughout the monitoring program, such as: Is the average habitat patch size increasing or decreasing? Are TES populations stable? Is the density of snags increasing or decreasing?, etc. (Noss 1990).

As mentioned earlier, the monitoring process will be effective only as part of a larger adaptive management effort, not just monitoring for the sake of monitoring. Adaptive management addresses uncertainty by recognizing several possible, alternative outcomes (multiple working hypotheses), and by implementing management actions in an experimental fashion (Walters 1986). It is in this framework that questions for the monitoring process are designed. If possible, alternative management strategies can be implemented side-by-side, or with a control site to facilitate analysis of results. The monitoring process should provide not only sequential data for certain variables through time, but also comparisons of the effectiveness of various "treatments" (management actions). Not surprisingly, adaptive management is characterized by a close relationship between research and management. The process works when results lead to improvements in management strategy (Irwin and Wigley 1993). At its best, adaptive management allows managers to keep pace when ecological data, economic conditions, and/or social values change (Salwasser, MacCleery, and Snellgrove 1992).

In summary, the cornerstone to good ecosystem management is a well-planned, experimentally based, monitoring program that will assess many ecosystem variables as well as TES population parameters. In an adaptive management framework, monitoring results are fed back into the management strategy, and efforts to conserve TES should be increasingly effective.

6 Implications of Ecosystem Management for the Army

From a scientific, ecological point of view, ecosystem management is a superior strategy for managing TES on a regional basis. This approach considers TES, biodiversity, and natural resources in a historical, spatial, and temporal context, providing managers with comprehensive information with which to make decisions. It may demand more involvement by the training community in land management issues. Of course, there will be difficulties involved in implementing ecosystem management. The discussion thus far reveals conceptual uncertainties as well as differences in approaches to ecosystem management. The Army will have to make tough decisions about the nature of ecosystem management for TES management on military lands. Some components of ecosystem management will easily fit into existing programs, such as the Integrated Training Area Management (ITAM). Land Condition Trend Analysis (LCTA) can serve to inventory Army lands and locate natural features such as wetlands or TES populations. The Land Rehabilitation and Maintenance (LRAM) program continues to restore degraded areas, to ensure their long-term availability for training as well as to promote their natural functions in the landscape. The Training Requirements Integration (TRI) program could play a critical role in comprehensive landscape planning for all land uses on the installation. The best opportunity to implement ecosystem management will be the development and implementation of Integrated Natural Resource Management Plans (INRMP), which will include data and decisionmaking components of ITAM, TES management, cultural resource management, and other natural resource management issues, in one comprehensive document. As ecosystem management is incorporated, the ten DOD principles of ecosystem management will provide important guidance. The following discussion attempts to evaluate the implications of these ten principles for both land managers and trainers on installations, as ecosystem management is explored further by the Army.

Maintain and Improve the Sustainability and Native Biological Diversity of Ecosystems

This aspect of ecosystem management reorients land management toward natural communities and ecosystems on Army lands. It suggests that managers likely will

recognize the native composition, historic structure, and natural functions of communities and ecosystems. Management goals may include restoring and sustaining natural systems in addition to traditional land use management goals such as timber production and agricultural leases. In some cases, traditional land uses may even be reduced in order to promote natural species and their habitats.

This principle suggests that the training community may wish to proactively evaluate the impacts of its mission on biodiversity and on the sustainability of impacted ecosystems. Efforts to document the carrying capacity of training land and to match activities with land condition would go a long way to promote sustainable use of military lands. Sustainable land use does not disrupt the natural functioning of the ecosystem, which allows the ecosystem to repair itself and support further land use. Impacts to biodiversity could be evaluated through risk assessment and minimized through various management techniques and scheduling decisions. If these efforts are made proactively, before there is a conflict between training and ESA compliance, the military may avoid future conflicts whereby training might be prohibited. Present conflicts can be resolved through this approach as well, but training should ultimately be supported by avoiding conflicts.

Administer With Consideration of Ecological Units and Timeframes

Most Army installations were designated decades ago. It is safe to assume that little to no effort was made to determine the ecological constraints on the ecosystems where military installations were established. This common situation presents difficulties for land managers, since efforts to conserve natural resources or protect TES can be overwhelmed by impacts from land use activities beyond installation boundaries. The Army can counteract this by cooperating with neighboring landowners (especially if public) to reduce transboundary impacts and to actively coordinate multiple land management programs in concert. The size and characteristics of the area in which cooperation is valuable will depend on the management goal at hand. For TES, installation personnel may want to promote coordination with any landowner whose activities affect TES populations on the installation or in the region. For water resource issues, cooperation throughout the watershed should be sought. At the very least, a larger geographic perspective can provide a more accurate picture of cumulative impacts on ecosystems and TES. Even within the boundaries of a single installation, activities in one area have real impacts on the condition of other areas. Negative impacts to the ecosystem and biodiversity can be minimized by coordinating land use activities on the installation and by understanding the resultant effects of each activity on other areas of the installation. (For example, fertilization for the revegetation of some areas can lead to nitrogen runoff, which pollutes certain wetland

communities and can alter their composition and function; DA 1994). Land managers, real property planners, and military training commanders can work together and evaluate these landscape patterns.

Ecological and evolutionary processes can occur over long periods of time. Even if military or other land use effects are not immediately evident, they may have negative future consequences for both the ecosystem and for land managers. Over time, cumulative impacts can lead to reduced options and can potentially restrict training in the future. If military or natural resource land use decisions are made with an awareness of long-term impacts and time scales, future damage can be minimized.

Support Sustainable Human Activities

The Army has the responsibility to evaluate how military activities interact with the natural world. When are they compatible? At what point do they compromise ecological integrity? How does installation land use fit into the larger picture of land uses and ecological processes? Will TES conservation occur where military activities do not, or will military action take place in areas of little importance to TES?

Sustainable land use decisions on installations will be very difficult to make, especially in the short term. Often, Army lands are managed for hunting, wood products, grazing, recreational, and other "multiple uses." These uses may be more damaging to TES populations, on a landscape scale, than military training. It may be necessary to reduce the acreages dedicated to these uses, in order to support the mission and comply with environmental legislation.

There will be situations where ecosystem management and TES conservation directly conflict with military training goals. A long-term perspective suggests that any compromises in favor of ecological integrity will increase benefits such as ecosystem services, long-term availability of functional training lands, reduced compliance pressures, and reduced restrictions on training. Whenever the choice is made to compromise ecosystem integrity to allow training, the consequences should be identified and understood through risk assessment so that appropriate mitigation measures can be chosen. At the very least, activities can be undertaken with an understanding of their true impacts and implications.

Despite the inevitable conflicts, the integration of sustainable land use and conservation on a landscape scale is a central theme of ecosystem management, and it promises to provide increased flexibility to the Army after TES populations stabilize (J. Young; R. Costa; and F. Samson, Regional Wildlife Ecologist, U.S. Forest Service, professional

discussion). Activities can be modified to mimic natural processes, natural resilience can be maintained, and damage can be limited to areas that can physically and ecologically sustain it.

This can be accomplished within the military context if creative, flexible management approaches are used. Camp Dodge, IA, is assessing whether tracked vehicle disturbances mimic the historical role of bison in maintaining native prairie biodiversity. At Camp Navajo, AZ, a 600-bed barracks was located on a site that was previously built upon. This resulted in no TES conflicts and no additional fragmentation to natural areas (Mark Imlay, Natural Resources Program Manager, Army National Guard Bureau, professional communication). Unfortunately, there is not a large body of biological theory or solid data to guide the Army in how best to direct military activities in order to reduce ecosystem impacts. This is one area of research in which the Army could become a leader.

Develop a Vision of Ecosystem Health

Developing a vision of ecosystem health will require site-specific considerations. It is almost assured that installations in different regions and different ecosystems will develop different desired future conditions, management objectives, and focal elements around which to plan. Since private and urban lands are able to support human-adapted species, Federal lands may consider giving those species low priority, and not expend any special effort to maintain them (R. Costa). TES species and their structural and functional ecosystem requirements will likely be given high priority during the planning process at all installations. However, long-term planning shouldn't focus too narrowly on them, since conflicts may exist between TES or between TES and other important ecosystem components. One suggestion is to balance three related goals: (1) endangered species; in aggregate through a habitat approach, if possible, (2) endangered or rare ecosystems/communities, and (3) indigenous ecosystems/communities (M. Imlay). Achieving balance requires broad collaboration among all interested parties (Federal and state agencies, private organizations, nongovernment organizations, and the public). During the process, existing social and economic conditions can be considered. In addition, the various roles in which interested parties can support sustainable ecosystems can be determined.

Develop Priorities and Reconcile Conflicts

Developing priorities and reconciling conflicts is the first step to reaching a vision of ecosystem health. The DOD states that an ecosystem management approach should include mechanisms for establishing priorities among various management and land use objectives and for conflict resolution during the selection of both management objectives and the methods taken to meet objectives. This principle highlights the need for open communication among land users (e.g., trainers and natural resource managers), and among multiple land owners. Regional workshops are suggested as one way to enhance dialog and to coordinate efforts among various parties.

Develop Coordinated Approaches for Ecosystem Health

Ecosystem management requires consideration of scale, fragmentation, connectivity, and land use patterns on and surrounding each installation, especially if a regional approach is forged with neighboring landowners. How do Army installations fit into the larger picture? Most likely, installations are a small but important part of a regional ecosystem, such as the long-leaf pine ecosystem in the southeast, or the Sonoran Desert of the southwest.

The political process of assigning appropriate boundaries and gathering the various players is not clear. Regional ecosystems could be officially designated at the Federal level, through a multiagency committee; players may be mandated or requested to participate. Alternatively, regional offices and individual sites may gradually build partnerships one at a time, until regional units are consolidated. Administrative models for ecosystem management are discussed by Wuichet (1995). There will most likely be a different administrative and planning area for each issue. The boundaries can be fluid, and they may change through time as concerns and knowledge change. The critical technical aspect of the unit is its ecological integrity.

If nearby lands are public, cooperative ecosystem management might be a welcome solution for everyone struggling with conservation of TES. In 1994, representatives from seven Federal agencies, including the DOD, signed a Memorandum of Agreement on implementation of the ESA to promote cooperation in regional and national efforts. Installations that have both public and private neighbors may consider working with public agencies initially, and then work together with the public agencies to seek private cooperation.

The Army may or may not be successful in gaining private landowner cooperation, since many private landowners resist TES conservation under the assumption that it

will reduce the flexibility and profitability of their land. However, both Fort Bragg, NC, and Eglin Air Force Base (AFB), FL, have had success in educating nearby private landowners about the value of ecosystem management. In those cases, resistance to ecosystem management, especially burning, declined after the installations went ahead with ecosystem management programs and the local community saw the positive changes they made in wildlife habitat (Mark Cantrell, Biologist, U.S. Fish and Wildlife Service, professional discussion; Stephen Seiber, Chief of Forest Management Branch, Natural Resources Division, Eglin Air Force Base, FL, 6 December 1994, professional discussion). Eglin AFB also has an active public relations campaign to reduce conflict over ecosystem management and to facilitate direct cooperation within the region. In some cases, cooperation may be improved when a third party (a not-for-profit organization, such as TNC, or a state agency) plays a coordinating role in the region and makes the initial contact with private landowners. Financial incentives, through the Army or through the Federal government, may be worthwhile.

Regional players can participate in joint planning efforts. They can coordinate and manage the data from inventories that document the natural disturbance regimes, TES populations, boundary ecotones, and land use patterns for the entire region. These efforts can establish the ecological and landscape context for installation land management. Furthermore, if nearby land owners coordinate management activities, the region should be more resilient and support healthier TES populations than the Army land unit could independently. This can serve to shift the responsibility of TES conservation to all landowners in the region as conservation goals are met cooperatively, instead of the Army striving to address TES issues in isolation. The degree to which that responsibility may be lifted from each Federal landowner is yet to be determined. Difficulties such as accountability for each partner's share of the responsibility are potential roadblocks.

Although planning and perspective should be regional, management actions will be carried out on portions of each installation. Identifying installation management units and prescribing their management is an important process. Eglin AFB has developed a useful approach for prioritizing areas for management. They categorized their ecosystems according to "naturalness," from Type I (closest to natural state) to Type IV (urbanized development), quantified the number of acreages in each category, and refined the site descriptions according to site quality and species composition. A management plan was developed for each site according to its naturalness category. As this process takes place, proper scale and pattern, and relationships across the landscape can be incorporated, so management of one area of the installation does not counteract management of a different area.

Rely on the Best Science Available

Ecosystem management requires an understanding of the complexities of the natural ecosystems on an installation. Although scientific knowledge is far from complete, much is known that can be implemented immediately. To capture and use the best science available, managers will need to update their knowledge continually. This may require more time spent off the installation interacting with the scientific research community and attending workshops. It may require land managers to interact more closely with other Federal agencies to coordinate lessons learned. An efficient solution may be to invite researchers onto the installation to perform original, experimental research and to experiment with various management alternatives in a scientific manner. This can have minimal impact on the training community if field research is scheduled around training activities.

Use Benchmarks to Monitor and Evaluate Outcomes

Using benchmarks in ecosystem management will alter the way land managers evaluate progress. Under ecosystem management, specific and appropriate indicators will be monitored to assess the success of management actions. Quality assurance and quality control mechanisms will be incorporated to ensure timely and effective management efforts. This characteristic of ecosystem management is not expected to directly impact the training community.

Use Adaptive Management

The final step in the initial process of ecosystem management is to coordinate knowledge about the natural ecosystems, management objectives, information gaps, and compliance requirements through a monitoring program. The program should be established in an adaptive management framework, where knowledge continually improves through the acquisition of data. That data are then used to evaluate and improve management strategies continually through time. The Army may wish to expand the LCTA program to perform long-term monitoring functions in a standard, yet flexible way. Each manager will have to analyze installation data over time, and make appropriate management adjustments through adaptive management.

As part of an adaptive management approach, research will be required increasingly to support management goals; objectives will depend more on integrating management and research. There is urgent need for: the refinement of classification schemes, studies of the relationships between population processes and landscape patterns, the

identification of keystone species and appropriate ecosystem indicator parameters, the identification of baseline variation in ecosystems, etc. Managers will not be solely responsible for addressing these questions, but enough variation exists among sites and among regions that management would be strengthened by on-site research of these issues. Some research questions can be answered through proper experimental design of management actions and statistical analysis of data from the monitoring program.

This aspect of ecosystem management should have minimal impact on the training community. However, as trainers work with land managers to plan management objectives and strategies, they should realize that land management goal, objectives, and strategies may change as the knowledge base is improved through the adaptive management process.

Implement Through Installation Plans and Programs

To create the vision of ecosystem health discussed in this report, ecosystem management could be implemented throughout all programming at the installation, the Army, and the DOD. Since all interested parties should be involved in the planning process, it makes sense that they also participate in the implementation. This may foster a closer working relationship between land managers and trainers, administrators and master planners. If activities are coordinated and the linkages are explicitly recognized, ecosystem management can be more efficiently and effectively implemented. This aspect of ecosystem management may require the training community to evaluate its relationship to other activities on the installation, participate in master planning activities, and understand the linkages between training activities and the health of the ecosystem. Communications between trainers and land managers can and should be improved for ecosystem management to be a success. To facilitate this change in culture, it may be beneficial to create a short-term plan, medium-term transitional phase, and longer-term ecosystem management program in concert. The responsibilities of major players and the nature of management objectives would most likely be different for each time frame. The overall desired future condition of the installation and the future roles of the various parties may be different from today's world, but a period of transition can make the process easier.

The lack of information and the process-oriented framework for ecosystem management dictates a decentralized land management strategy. Detailed mandates on the procedures for ecosystem management are not appropriate, due to the nature of ecosystem management. However, high-level involvement is critical. The Department of the Army can facilitate much-needed improvements in communications, information

(such as continued training for installation personnel), and financial support. Funding will have to facilitate a shift away from dependence on traditional commodity production toward long-term planning/harvesting and creative enterprise (such as native seed production). Funding among Federal and state agencies could create interagency teams that can serve the entire region's needs (such as fire management teams; J. Young). High-level initiatives can clarify the appropriate desired future condition for various regions of the country, designate or produce regional or national classification systems, and facilitate interagency cooperation. The combination of high-level support and installation-level flexibility and creativity will allow full implementation of ecosystem management across the country.

7 Summary

In the future, TES conservation will most likely take place within an ecosystem management framework. Political pressures are mounting against expensive, last-ditch efforts to save individual species, but public support for TES conservation remains high. This seems to indicate that the public would support a new approach to TES management. The USFS (USDA 1992), the Bureau of Land Management (BLM; USDI 1993), and FWS (USDI 1994) have formally declared ecosystem management as the preferred method for managing natural resources.

Of primary importance to the Army is the ability to train troops and test weapons on its land. Ecosystem management is a legitimate approach for integrating Army activities with TES conservation. Instead of focusing on a few species, ecosystem management provides potential to optimize for the needs of many species, including humans.

In the short term, ecosystem management will probably place increased responsibility on the training community for evaluating and managing impacts on ecosystem integrity and biodiversity, although emphasis will probably remain on TES in particular. New approaches to minimizing impacts are needed, such as attempting to mimic natural disturbance patterns when impacts are unavoidable. Ecosystem management should also provide improved data with which to make land use decisions. By understanding ecosystems, we can have a better understanding of the impacts on TES and on other sensitive resources. When a decision is made that may have negative impacts on the ecosystem, managers should have an improved ability to restore the system and protect its integrity. If the land is used in a sustainable manner, natural processes are facilitated, and landscape connectivity is established, then on a landscape or regional scale, habitat availability should stabilize, and populations and ecosystems should be able to recover from the perturbations they experience. This has the potential to lead to increased flexibility for training under the ESA, compared to current compliance requirements. However, this increased flexibility will probably only exist in the medium- to long-term, and will depend on the health of installations' ecosystems and the effort demonstrated by natural resource managers to implement a proactive ecosystem management strategy.

In some cases, intensive approaches to manage individual species will still be necessary under the Endangered Species Act. However, there are examples where the Federal government has been willing to relax ESA requirements in order to give ecosystem management a chance to serve human and TES needs (Babbitt 1994). Another approach is to implement ecosystem management narrowly, with specific focus on TES, until populations recover, and then expand the scope of management (MacKenzie 1993). However, this runs the risk of making the same mistakes we make now, because by ignoring the ecosystems on which TES depend, we threaten them further. No matter how ecosystem management is integrated with current approaches, in the medium- to long-term, ecosystem management will not only support current TES, but should prevent other species from declining to threatened or endangered status.

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APPENDIX A: List of Experts Interviewed

Mr. Terry Cook, Texas Nature Conservancy

Mr. Ralph Costa, Recovery Coordinator, Southeast Region, Fish and Wildlife Service

Mr. John Edgington, Department of Forestry, University of Illinois

Dr. David Ewert, Director of Science and Stewardship, Michigan Nature Conservancy

Dr. Lee Graham, Wildlife and Fisheries Sciences, University of Arizona

Ms. Kathy Jope, Chief of the Division of Natural Resources, Pacific Northwest Region, National Park Service

Dr. Fred Samson, Regional Wildlife Ecologist, U.S. Forest Service

Ms. Jora Young, Director for Science and Stewardship, Florida Nature Conservancy

Appendix B: Glossary

abiotic: Nonliving; as applied to the physical and chemical components of the biosphere or an ecosystem (Allaby 1992).

adaptive management: An approach to natural resources management that views management as a continual learning process. It includes (1) the bounding of problems in terms of objectives, constraints, and other policy factors; (2) analysis of ecosystems, including dynamic factors and management assumptions and predictions, such that errors are detected and used to promote further knowledge; (3) use of statistics and hypotheses testing with an awareness of uncertainty and its effects on management decisions; and (4) design of policies that combine management goals with continued probing for further understanding (Walters 1986).

adaptive traits: Characteristics of a species or population that have been favored by natural selection in the past and are still useful in the current environment.

agricultural conversion: The process of removing the native flora from an area and replacing it with agricultural production systems, usually nonnative plant and/or animal species.

antagonistic: Harmful, detrimental.

biodiversity, biological diversity: The variety of genetic combinations, species functions, and associations occurring in an area, and the degree representative of the indigenous flora and fauna. It is a dynamic principle that contains highly interdependent components at many organizational levels (DA 1994).

Biological and Conservation Data System (BCD): A state-of-the-art information management tool designed by The Nature Conservancy to assist in an integrated approach to biodiversity conservation (TNC 1993).

biome: A biological subdivision of the Earth's surface that broadly corresponds to climatic conditions and is defined in terms of all living organisms and their relationship to their environment (Allaby 1992).

bioregion: A territory defined by a combination of biological, social, and geographic criteria, rather than geopolitical considerations; a system of related, interconnected ecosystems (USDI 1993).

biosphere reserve: The model for land protection and ecosystem management developed for the United Nations' Man and the Biosphere (MAB) projects; certain high quality natural ecosystems are protected from human use, but are surrounded by large zones of increasingly intensive human activities (Ray and Gregg 1991).

biota: Plants and animals occupying a location (Allaby 1992).

biotic: Living; as applied to the components of the biosphere or an ecosystem (Allaby 1992).

biotic integrity: The ability of an environment to support and maintain a biota (both the structural and functional components) comparable to the natural habitats of the region (Karr 1993).

carrying capacity: The maximum number of individuals or the maximum land use intensity that can affect a given area of habitat without resulting in irreversible damage to the habitat and without causing social stresses that result in population reduction (McNeely et al. 1990).

climax community: The final stage of plant succession, in which the vegetation of an area maintains a self-perpetuating state that is in equilibrium with the environment (Allaby 1992).

community: A grouping of populations of different species found living together in a particular environment (Allaby 1992).

composition: General makeup; as applied to the identity of the various elements of a community or an ecosystem.

competition: One type of interaction where individuals or species compete for resources such that the growth and survival of one or more of the species or individuals are reduced.

conservation, biological conservation: Active management to ensure the survival of the maximum diversity of species, and the maintenance of genetic diversity

within species; implies the maintenance of ecosystem functions; embraces the concept of long-term sustainability (Allaby 1992).

conserve: The act of practicing conservation. According to the Endangered Species Act, to conserve a species is to use all methods and procedures that are necessary to bring listed species to the point where such measures are no longer necessary (Rohlf 1989).

conspecific: A member of the same species.

corridor, habitat corridor: A relatively narrow strip of habitat that crosses a matrix of nonhabitat land and serves to connect larger areas of habitat.

cumulative effects: Effects on the environment that result from the incremental impact of any action when added to other past, present, or future actions (modified from Hunsaker 1992).

desired future condition: A description of management goals for a land management unit; the description should be constructed with the input of all interested parties in the region and should include clear goals for species', communities', and ecosystems' composition and/or structure and function across the landscape.

dispersal: The movement of an organism away from its breeding site or birth site (Allaby 1992).

disturbance: Any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Turner 1989).

diversity: Variety, heterogeneity; see biodiversity.

dominance: The status of the most predominant (largest, most numerous) species within a forest, or other vegetative community; typically calculated by multiplying basal area with the number of individuals of the species (Müeller-Dombois and Ellenberg 1974); used frequently in plant community classification schemes.

ecosystem services: All of the goods and services provided to humanity by natural ecosystems; examples include wood products, fertile soils, genetic variation (the "genetic library"), clean water, and clean air, etc.

ecological species group: A unique group of understory species that have been correlated with certain physical conditions, and thus, as a group, can be used as indicators of those conditions; used in ecological site classification systems (Barnes 1993).

ecoregion: A large geographical area delineated by distinct ecological characteristics of the natural and human environment.

ecosystem: Dynamic and interrelating complex of plant and animal communities and their associated nonliving environment (USDI 1994).

ecosystem health: The condition when a system's inherent potential is realized, its condition is stable, its capacity for self-repair, when perturbed, is preserved, and minimal external support for management is needed (Karr 1993).

ecosystem processes: The aggregate of all interactions among the various biotic components of an ecosystem (e.g., migration, pollination, predation), between the abiotic and biotic components of an ecosystem (e.g., nutrient uptake, erosion, respiration) and natural events and cycles (e.g., fire regimes, hydrologic cycles, hurricanes).

ecosystem management: Protecting or restoring the function, structure, and species composition of an ecosystem, recognizing that all components are interrelated (USDI 1994).

ecotone: A zone of transition between habitat types (Ricklefs 1979).

edge: The abutment of distinctive vegetation types (Ricklefs 1979).

emergent properties: Properties of higher levels in a system that are not obvious from the properties of lower levels in the system; properties that become apparent as a coarser-grained level of resolution is used by the observer; properties that are unexpected to the observer because of incomplete data (Allen and Starr 1982).

function: The interactions among the elements of an ecosystem (Forman and Godron 1986); the occurrence of the natural ecosystem processes.

fragmentation, habitat fragmentation: The process whereby a larger, continuous area is both reduced in area and divided into two or more pieces (Primack 1993).

gap analysis: A GIS-based process that identifies unprotected species or communities by overlaying data sets of vegetation maps, species distributions, areas managed for biodiversity, and other landownership data (Scott, Csuti, and Caicco 1991).

genetic diversity: The amount of variation in allele frequencies and distribution, usually within a population or a species.

geographic information system (GIS): A set of computer hardware and software for analyzing and displaying spatially referenced features (such as points, lines, or polygons) with nongeographic attributes (such as species, age; Johnson 1990).

gradient analysis: A technique for studying the spatial patterns of vegetation based on gradients of environmental factors, species distributions, and community characteristics (Whittaker 1967).

guild: Two or more co-occurring species' populations that exploit the same type of resources in similar ways (Koford et al. 1994).

habitat: The living place of an organism or community, characterized by its physical or biotic properties (Allaby 1992); habitats can be described on many scales from microhabitats to biomes.

importance values: The sum of the relative frequency, relative density, and relative dominance for a given species (Müeller-Dombois and Ellenberg 1974); used to quantitatively describe plant communities.

Index of Biotic Integrity (IBI): An index composed of 12 ecological measurements that assesses the condition of both the elements and the processes of biodiversity; originally developed for use in Midwestern streams (Karr 1990).

indicator: A measurable surrogate for environmental end points, such as biodiversity, that are assumed to be of value to the public (Noss 1990).

interior habitat: An organism-defined portion of habitat that is not significantly affected by a different, adjacent habitat-type in the landscape, but is characterized only by its own compositional, structural, and functional attributes.

keystone species: A species whose presence is crucial in maintaining organization and diversity in their communities and who are much more important than the

abundance of the species would suggest (modified from Mills, Soule, and Doak 1993).

land ethic: A philosophy developed by Aldo Leopold during the first half of the 20th century that reconciles and integrates human economic activities with biological conservation; the summary moral maxim states: "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." (Callicott 1991).

landscape: A heterogenous land area composed of interacting ecosystems that are repeated in similar form throughout; landscapes are variable in size (Forman and Godron 1986).

landscape dynamics: The flux of energy, mineral nutrients, and species among the component ecosystems on a landscape, and the resulting changes in those ecosystems (Forman and Godron 1981).

landscape ecology: The study of the structure, function, and change in a heterogenous land area composed of interacting ecosystems (Forman and Godron 1986).

landscape equilibrium: A condition whereby the overall structure and function of a landscape do not change, although component patches within the landscape may undergo change through time.

life history, life history strategy: An organisms' patterns of growth, reproduction, and longevity that are related to specific demands for survival in a particular place at a particular time (Barbour, Burk, and Pitts 1987).

litter: An accumulation of dead plant remains on the soil surface (Allaby 1992).

microhabitat: The biotic and abiotic components of an environment at a scale that affects individual organisms independently.

Muir, Muir's "preservationists": A facet of the conservation movement in the early 1900's, led by John Muir, advocated public appreciation and preservation of wilderness; they believed that religious, aesthetic, contemplative, and relaxing uses of the natural world were superior to commercial uses (Callicott 1991). These powerful ideas remain imbedded in the conservation movement today.

mutualistic: Mutually beneficial.

natural: The state of being free of human influence; three indices can be substituted: (1) degree of change if humans were removed; (2) the amount of cultural, energetic subsidy necessary to maintain current functioning; and (3) the complement of native species currently present compared with presettlement (Anderson 1991); sometimes aboriginal human influence is included in the concept of "natural," while modern technological influence is always excluded.

natural resources: A subjective concept of the environment and various attributes and components of the environment that are capable of satisfying the needs and desires of humans (Hamilton 1994).

patch: A nonlinear surface area that differs in appearance from its surroundings (Forman and Godron 1986); the term used for distinct areas, such as ecosystems, on a landscape.

physiognomy: The form and structure of natural communities (Allaby 1992).

physiography: Pertaining to the physical geography (Mish 1989).

Pinchot, Pinchot's "wise use" advocates: A facet of the conservation community in the first half of the 20th century, led by Gifford Pinchot, advocated a philosophy that nature existed for humans to use, to provide the "greatest good for the greatest number for the longest time"; they equated conservation with development (Callicott 1991). These ideas remain powerful within American society today.

population: A group of individuals of the same species occupying an area small enough to permit interbreeding among all members of the group (Barbour, Burk, and Pitts 1987).

population viability analysis (PVA): A computer model-based analysis of the minimum number of individuals needed to maintain a population for a specified period of time.

redundancy: The condition in which an ecological function is performed by more than one species.

region: A large geographical area that is distinguished by certain characteristics (e.g., biological, ecological, social, political, economic).

resilience: The ability of a system to maintain its structure and patterns of disturbance in the face of disturbance; pertaining to the boundaries of stable behavior, events far from equilibrium, high variability, and adaptation to change (Holling 1986).

riparian: Pertaining to the boundary between water and land; normally represents the streamside zone and the area of influence of the stream (C. Martin, Research Wildlife Biologist, Waterways Experiment Station, Vicksburg, MS).

self-organization, self-renewal: Properties of cybernetic systems, whereby feedback mechanisms allow the system to return to equilibrium or a normal trajectory of change after experiencing a perturbation (O'Neill et al. 1986).

snag: A dead tree that remains standing.

species: One or more populations of individuals that can interbreed, but cannot successfully breed with other organisms (are isolated reproductively; Allaby 1992); for ESA compliance, any species, or any subspecies of vertebrate, that is granted protected status under the ESA.

species richness: A simple count of the number of species in an area.

stability: The propensity of a system to attain or retain an equilibrium condition of steady state or stable oscillation; having a resistance to departure from that equilibrium condition, and if perturbed, returning rapidly to that equilibrium condition (Holling 1986).

stand: An existing plant community that is relatively uniform in composition, structure, and habitat conditions; an aggregate of trees occupying a specific area with sufficiently uniform composition, age, and condition to be distinguished from the forest on adjacent areas (C. Martin, pers. comm.).

structure: The horizontal and vertical spatial arrangement, or configuration, of a habitat, community, or ecosystem.

succession: Sequential change in the vegetation at a particular location.

sustainable, sustainability, sustainable use: A level and method of resource use that does not destroy the health and integrity of the systems that provide the resource; thus the long term resource availability does not ever diminish due to such use.

threatened and endangered species (TES): Those species that are listed as threatened or endangered under the Endangered Species Act of 1973, and those species that are candidates or proposed as candidates for listing under the ESA.

triad model: A conceptual model for allocating land uses across a landscape that recognizes intensively managed lands, reserved lands, and multiple-use lands (Hunter and DeMagnadier 1994).

watershed: The geographic area that naturally drains into a given watercourse such as a stream or river.

Abbreviations and Acronyms

AEMB	Army Ecosystem Management Board
AEPI	Army Environmental Policy Institute
BCD	Biological and Conservation Data System
BLM	Bureau of Land Management
CEQ	Council on Environmental Quality
DA	Department of the Army
DOD	Department of Defense
DOI	Department of the Interior
ESA	Endangered Species Act of 1973
FWS	Fish and Wildlife Service
GIS	geographic information system
GPS	global positioning system
IBI	Index of Biotic Integrity
INRMP	Integrated Natural Resources Management Plan
LCTA	Land Condition Trend Analysis
LRAM	Land Rehabilitation and Maintenance
MAB	Man and the Biosphere
NBS	National Biological Survey

NPS	National Park Service
PVA	Population Viability Analysis
TES	threatened and endangered species
TNC	The Nature Conservancy
TRI	Training Requirements Integration
USACERL	U.S. Army Construction Engineering Research Laboratories
USDA	U.S. Department of Agriculture
USDI	U.S. Department of the Interior
USFS	United States Forest Service

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US Army Jefferson Proving Ground
ATTN: STEJP-EH-R
US Army Yuma Proving Ground
ATTN: STEYP-ES-E
Anniston Army Depot
ATTN: SDSAN-DPW-PED
Blue Grass Army Depot
ATTN: SDSBG-EN
Letterkenny Army Depot
ATTN: SDSLE-ENN
Red River Army Depot
ATTN: SDSRR-OE
Sacramento Army Depot
ATTN: SDSSA-EL-MO
Sierra Army Depot
ATTN: SDSSI-ENV
Tobyhanna Army Depot
ATTN: SDSTO-EM
Tooele Army Depot
ATTN: SDSTE-PWE-E
US Army Depot-Hawthorne
ATTN: SMCHW-ORE
Pueblo Army Depot Activity
ATTN: SDSTE-PU-SE
Savanna Army Depot Activity
ATTN: SDSLE-VA
Seneca Army Depot Activity
ATTN: SDSTO-SEI-PE
Umatilla Army Depot Activity
ATTN: SDSTE-UAS-EVE
McAlester Army Ammunition Plant
ATTN: SMCMC-DEL
Holston Army Ammunition Plant
ATTN: SMCHO-EN
Indiana Army Ammunition Plant
ATTN: SMCIN-EN
Iowa Army Ammunition Plant
ATTN: SMCIO-PPE
Kansas Army Ammunition Plant
ATTN: SMCKA-OR

Lake City Army Ammunition Plant
ATTN: SMCLC-EN
Lone Star Army Ammunition Plant
ATTN: SMCLS-SEE
Longhorn/Louisiana Army Ammo Plant
ATTN: SMCLO-EN
Milan Army Ammunition Plant
ATTN: SMCMI-IO
Mississippi Army Ammunition Plant
ATTN: SMCMS-CA
Newport Army Ammunition Plant
ATTN: SMCNE-EN
Radford Army Ammunition Plant
ATTN: SMCRA-OR
Sunflower Army Ammunition Plant
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